ELECTRICITY

ITS MEDICAL AND SURGICAL APPLICATIONS, INCLUDING RADIOTHERAPY AND PHOTOTHERAPY

BY

CHARLES S. POTTS, M.D.

PROFESSOR OF NEUROLOGY, MEDICO-CHIRURGICAL COLLEGE; FORMERLY INSTRUCTOR IN ELECTRO-THERAPEUTICS AND ASSOCIATE IN NEUROLOGY, UNIVERSITY OF PENNSYLVANIA MEDICAL DEPARTMENT, PHILADELPHIA

WITH A SECTION ON ELECTROPHYSICS, BY HORACE CLARK RICHARDS. PH.D. PROFESSOR OF MATHEMATICAL PHYSICS IN THE UNIVERSITY OF PENNSYLVANIA, AND A SECTION ON X-RAYS, BY HENRY K PANCOAST, M.D. PROFESSOR OF RÖNTGENOLOGY IN THE UNIVERSITY OF PENNSYLVANIA, MEDICAL DEPARTMENT, PHILADELPHIA

WITH 356 ILLUSTRATIONS AND 6 PLATES

LEA & FEBIGER
PHILADELPHIA AND NEW YORK
1911

PREFACE

The author has long been convinced that non-medicinal methods of therapeusis do not receive in either the medical curriculum or in medical practice the attention merited by their real value. It follows necessarily, therefore, that these remedial agents are not appreciated and utilized as fully as they should be by the regular practitioner.

Of these one of the most important is the electrical current, the uses of which in medicine and surgery have developed so enormously in the last fifteen years that it is impossible to discuss all of them fully in a single volume of convenient size. Nevertheless, in the following pages an effort has been made at least to mention all the ways, direct and indirect, in which electricity may be of assistance in the diagnosis and treatment of both medical and surgical affections, and to give detailed consideration to the action and the methods of employing the current in the various conditions of disease in which it is beneficial. To possess any value, a work on such a vast field cannot be based on the experience of any individual. It must also reflect the knowledge of the great body of investigators and observers who have developed the subject to its present status. In aiming to give a survey of the entire field, the author has endeavored to exercise conservative judgment and to offer a work suitable both for students and practitioners.

For the intelligent use of electricity as a remedial agent, a knowledge of the changes in the tissues and functions of the various organs of the body caused by its passage is essential. What may be termed electro-physiology is therefore most important. In treating the whole subject an original plan has been adopted. The custom hitherto has been to consider the physiological action, therapeutic uses, and methods of application of each form of current separately. In this volume, on the contrary, these subjects have been discussed collectively, according to a medical rather than a physical subdivision. In other words, instead of devoting one section exclusively to the constant current, another to the static current, and so on, the author has grouped these modalities according to the effects produced. Thus, for instance, in

discussing the action of the electric current on metabolism, the actions of all modalities on this process have been grouped. A similar plan has been followed in the description of therapeutic procedures, for instance, the methods of using and comparative values of all forms of current in stimulating motor nerves and muscles have been presented in one chapter. This plan seems to offer distinct advantages, since the indications for treatment lead at once to the determination of the question whether electricity would be of benefit, and if so, the form of current which would secure the best results. Such an arrangement is scientific instead of empirical. If any excuse is necessary for its novelty and originality, it may be said to be the only plan which affords the highest practicality for the purposes of the physician and surgeon, as it presents the subject of electricity from the standpoint of its clinical uses, instead of following the arrangement customary in books on physics and bringing in the medical applications incidentally and disconnectedly. It necessitates, of course, some repetition, which is rather an advantage, as are also the copious cross-references, enabling the reader to pursue any desired line of knowledge with regard to the action and uses of the various modalities. Similarly, in the sections on the therapeutics of individual diseases, the reader will find convenience in the references to the physiological action of the form of current mentioned.

Use has been made of a number of text-books and monographs, especially those of Jones, Massey, Snow, Freund, Cohn, Strong, Guilleminot, Mosher, Hedley, Rockwell, Turner, Jacoby, and Williams. Reference to others is made in the text. The author is indebted to these works and to manufacturers for many of the illustrations. He is especially under obligation to Dr. Mosher for the use of his vastly superior diagrams of motor points. The sections on Physics and *X*-rays have been respectively written by Drs. Richards and Pancoast, of the University of Pennsylvania, while a large portion of the chapter on Diseases of the Throat, Nose, and Ear was written by the late Dr. W. G. B. Harland.

Lastly, the author must express his appreciation of the patience and courtesy of the publishers.

C. S. P.

1728 Chestnut Street,
Philadelphia, 1911.

CONTENTS

SECTION I

ELECTRICITY

SECTION II

ELECTROPHYSIOLOGY

SECTION III

ELECTRODIAGNOSIS AND ELECTROPROGNOSIS

CHAPTER VIII

CHAPTER IX

CHAPTER X

SECTION IV

GENERAL ELECTROTHERAPEUTICS

CHAPTER XI

CHAPTER XII

CHAPTER XIII

CHAPTER XIV

SECTION V

METHODS OF OBTAINING GENERAL AND LOCAL EFFECTS BY THE INDIRECT ACTION OF ELECTRICITY

CHAPTER XV

SECTION VI

SPECIAL ELECTROTHERAPEUTICS

SECTION VII

THE APPLICATION OF THE RÖNTGEN RAYS IN MEDICINE

CHAPTER XXVIII

CHAPTER XXIX

CHAPTER XXX

CHAPTER XXXI

ELECTRICITY IN MEDICINE AND SURGERY

SECTION I

ELECTRICITY

CHAPTER I

ELECTROSTATICS

FUNDAMENTAL PHENOMENA

Electrification.—It has been known at least since the time of Thales (600 B.C.) that when a piece of amber or similar material is rubbed it becomes endowed with the property of attracting light bodies. For a long time the science of electricity was practically summed up in this isolated experiment, and it was not until the time of Elizabeth that Dr. Gilbert, Court Physician to that monarch, laid the foundations of the modern science. Gilbert showed that this property of *electrification* (a name which he derived from the Greek word for amber) is possessed by many other substances, and it has since been shown to be probable that the phenomenon is produced in a greater or less degree whenever two dissimilar bodies are brought into contact. When a body manifests the property of electrification it is said to be *electrified*, or to possess an *electric charge*. A body may receive a charge not only by being rubbed, but also by touching a previously electrified body. In this latter case it is said to be electrified *by conduction*.

Electrostatics.—Electrical phenomena may be broadly divided into two main classes: (1) Those dealing with charges at rest, and (2) those attending the transfer of a charge. The division of the science dealing with the former is called *electrostatics*, while the latter will be discussed later as constituting the phenomena of the *electric current*. Formerly the terms frictional and voltaic electricity were applied to these divisions; but this classification is an unfortunate one, as it implies that the phenomena are produced by two different agencies, while in fact they are fundamentally but one.

Conductors and Non-conductors.—While the property of electrification is a general one, bodies may be roughly divided into two classes according to the manner in which a charge becomes distributed upon them. Some bodies when electrified in any one part, either by friction or by conduction, distribute the charge over their surfaces, while with others the effect is confined to the place where it is produced. These classes are known as *conductors* and *non-conductors*, or *insulators*, respectively. The distinction, however, is not a sharp one, as all substances conduct to some extent. The best conductors are the metals and carbon, next to which may be placed acids and solutions of salts in water. Pure water is a very poor conductor, but an extremely small amount of impurity is sufficient to give it considerable conductivity, so that for practical purposes it may here be classed with good conductors. Among the best insulators are glass, shellac, silk, paraffin, ebonite, and dry air. Between these extreme cases may be mentioned a number of substances, such as paper, wood, cotton, etc., which permit conduction, but much less readily than the substances first named. The human body is a good conductor on account of its fluids, but as the epidermis when dry is a very poor conductor, the body as a whole offers considerable opposition to the passage of a charge.

The contrasting properties of conductors and non-conductors are important in the construction of electrical apparatus. Where it is desired to transfer electrical charges from one place to another or to distribute them over a surface, metallic wires or plates are used. On the other hand, in order that charges may be confined to a desired location and not be dissipated, the conductors must be separated or insulated from other conductors by non-conducting materials. For this reason conducting wires are covered with silk or some other insulator, and ebonite or glass[1] handles and supports are used on many electrical instruments.

Two Kinds of Electrification.—If a glass rod and a piece of silk are rubbed together and then separated, both bodies are found to be electrified. In some respects, however, the charge on the glass differs from that of the silk. The glass and the silk attract each other; but two pieces of glass electrified in the same manner will repel each other. Again, when a light conductor, such as a gilded pith ball, is electrified by contact with the glass, it will be repelled by this but attracted by the silk. Two such conductors when charged by touching the same body will repel each other, but if one has touched the glass and the other the silk, they will attract each other.

When other substances are substituted for the glass and silk the same phenomena are observed, the charges produced having identical properties. Thus, when ebonite is rubbed with fur, the electrification of the ebonite is in all respects similar to that of the silk, while the fur receives a charge like that of the glass. These experiments show that there are two kinds of electrification, that both kinds are simultaneously pro-

[1] While glass itself is a very good insulator, there is a tendency for moisture to condense upon it, producing a surface conductivity. It is therefore coated with shellac when high insulation is desired.

duced, and that bodies differently electrified attract each other, while those similarly electrified repel.

Until the two bodies which have been rubbed together are separated no effect is observed. This indicates that equal quantities of the two kinds of charge are produced, which neutralize each other while they are together. It has in fact been found to be a general law that the production of one kind of electrification is always accompanied by the production of an equal quantity of the other kind.

In order to distinguish between the two kinds of charge, the glass or the fur is said to be *positively,* the silk or ebonite *negatively,* electrified.[1] This distinction is convenient as representing the opposite effects of the two kinds of charge. It must be remembered, however, that it is purely arbitrary, and that in the above experiments nothing essentially more positive has been observed about one kind than the other. In fact, there have recently developed reasons for believing that the opposite convention would have been more desirable.

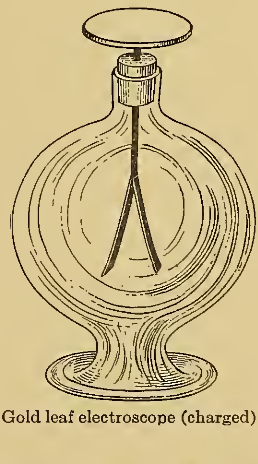
The Electrical Series.—The kind of electrification produced upon a body depends upon the material with which it is rubbed, as well as upon its own nature. Thus, glass rubbed with silk becomes charged positively, but if rubbed with fur it receives a negative charge. Different substances may be arranged in a list in such an order that when any two are rubbed together the one higher on the list will become positively charged. The following is a brief list of this kind:

1. Fur.
2. Wool.
3. Glass.
4. Cotton.
5. Silk.
6. Wood.
7. Metals.
8. Sulphur.
9. Ebonite.
10. Gun-cotton.

The position of a substance on such a list depends somewhat on the state of its surface, temperature, etc. For instance, when the surface of glass is ground it becomes electrified negatively if rubbed with silk.

The Electroscope.—A very convenient and delicate instrument which serves for the detection of the presence of an electrical charge is the gold leaf electroscope (Fig. 1). Two gold leaves hang side by side from the lower end of an insulated metal rod, the upper end of which terminates in a ball or plate. The leaves are protected from air currents by being placed in a closed glass vessel. If now a charge is given to the rod, the leaves, becoming similarly electrified, repel each other. On connecting the rod to the earth by a wire, or even touching it with the finger, the charge escapes and the leaves fall together again.

Fig. 1

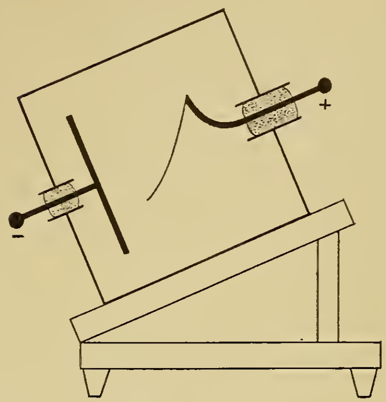


Gold leaf electroscope (charged).

[1] An older distinction was between *vitreous* and *resinous* electrification, the former corresponding to the positive charge.

Fig. 2 illustrates a more modern form of electroscope. A single gold leaf is used, which is attracted by an oppositely charged brass plate before which it hangs. A variation of the charge on the leaf changes the force of attraction and causes it to move. The motion is observed by viewing the leaf with a microscope of low power. This form, due to C. T. R. Wilson, has proved to be extremely sensitive.

Fig. 2



Wilson's electroscope.

Distribution of Charge.—When a charge is given to a conductor it distributes itself entirely on the surface, none whatever remaining in the interior. This may be shown by bringing a small insulated disk (called a proof plane) in contact with the inside of a hollow conductor and then testing it with an electroscope. No charge will be found on the proof plane, however highly the conductor was electrified. By the same method it may be shown that when the conductor is spherical the electrification is uniformly distributed over its surface; on an elongated conductor it is greatest at the ends; and in general the density of the charge increases with the curvature of the surface, becoming very great at sharp projecting edges or points if there are such on the conductor.

Effect of Points.—This property is very important practically. For if we attempt to charge a conductor on which there are points or sharp edges, the charge accumulates upon these, producing such intensity as to overcome the insulating properties of the air and electrify it. The electrified air is repelled from the points, carrying with it the charge, thus discharging the conductor and producing an electiical brush or breeze. The same property explains the manner in which pointed lightning rods protect a building by preventing the accumulation of electricity on it. On the other hand, sharp points and edges must be avoided on all parts of apparatus designed to retain their charge (p. 51).

THEORIES OF ELECTRICITY

The Electric Fluid.—Two rival theories as to the nature of these phenomena were proposed during the eighteenth century. The one more closely resembling the modern view is the one-fluid theory of Franklin. In this, all bodies are supposed to contain large amounts of an imponderable electric fluid, the parts of which repel one another while they attract ordinary matter. Matter containing an excess of this fluid is positively

electrified, while a deficiency below the normal amount corresponds to a negative charge. The other, the two-fluid theory, assumes the existence of two such fluids, to which were given the names of positive and negative electricity, attracting each other, but self-repellent. Unelectrified matter contains equal quantities of these two fluids; an excess of either constitutes a positive or negative charge.

The earlier fluid theories make no attempt to explain the mechanism of the electric forces. The omission led to the development by Faraday and Maxwell of the ether theory, which attributed the forces on charged bodies to stresses in the medium surrounding them. The insulating medium surrounding a conductor was hence termed a *dielectric,* because these electrical stresses are exerted *through* it. In this view the charging of a body consists in producing these stresses, and two oppositely charged bodies are analogous to two balls drawn together by a stretched elastic band. As electric forces are exerted even through a vacuum, it follows that the medium transmitting the stress is not ordinary matter, but an all-permeating substance which is known as the *ether.* This theory has proved very powerful in the development of electrical science.

The Electron Theory.—Within the last few years a number of facts have been discovered which have led to the formulation of a new theory which combines the points of view of the former theories, but surpasses them in being more definite. This is known as the *electron theory.* As in the theory of Faraday and Maxwell, the ether is the seat of the electric forces. As in Franklin's theory. the existence of a charge is due to the excess or deficiency of a single substance, which, however, in contradiction to Franklin, is identified with negative electricity. A positive charge, therefore, is produced by a deficiency and a negative by an excess of this substance. Like matter, it is discontinuous in structure, being composed of minute particles all alike in size and in the quantity of their negative charge. These particles, called *electrons,* have actually been observed and measured; their mass is somewhat greater than the two-thousandth part of that of the smallest known atom, that of hydrogen; their diameter, a few millionths of the diameter of an atom. So minute are they that the gain or loss of a body's mass, due to the greatest possible charge which can be put upon it, cannot be detected with a sensitive balance.[1]

By the action of stresses in the ether, as developed by Maxwell's theory, the electrons and atoms are mutually attracted, while two atoms or two electrons will repel each other. Each atom is normally combined with a number of electrons which are held to it by this mutual attraction. If this number is just sufficient to neutralize the positive charge of the atom, the system as a whole is uncharged. This represents the condition of the atom of a monatomic gas in its nor-

[1] Search for similar positive electrons has so far been fruitless, the smallest positively charged particle being found to have the dimensions of an atom and to be in all probability an atom itself.

mal state. An excess or deficiency of one or more electrons leaves the atom negatively or positively charged, a difference which depends on the nature of the atom and which determines many of its chemical properties.

In conductors some at least of the electrons are free to move from place to place; in insulators they have not this power. The limitation of the charge to the surface of conductors can be explained by the mutual repulsion of the free electrons and their attraction for the positively charged atoms. At sharp points the concentration becomes so great that electrons either escape or are drawn from the air molecules according to the sign of the charge upon the point.

Substances differ in their attraction for electrons; so when two different substances are put in contact, the one which has the greater attraction draws them from the other and becomes negatively charged, making the other positive. When the substances are insulators, this effect is confined to the atoms which are actually brought into contact, the friction increasing the number and perhaps assisting to loosen the attachment of the bound electrons. With conductors, contact at a single point is all that is necessary, the transfer continuing until the repulsion of the charge thus produced brings the process to an end.

The electron theory has proved itself capable of interpreting the most varied electrical phenomena. It offers a fairly definite answer to the often asked question, What is electricity? And while, of course, it must not be considered as furnishing a complete and ultimate solution of the problem, it assists greatly by offering a guide in the investigation of electrical processes.

MEASUREMENT OF ELECTRICITY

Force, Work, and Power.—In the discussion of electrical phenomena it is necessary to distinguish carefully between the mechanical quantities known as force, work, energy, and power. *Force* may be said to be any cause of a change in a body's motion; *work* is done only when a force acts through a distance. Force alone or displacement alone does not constitute work, but the combination of the two. Thus, if a moving body were free from all forces it would continue to move uniformly, but no work would be done. Again, if a heavy body is held at rest in the hand, the earth exerts a downward force of attraction on it, which is called the *weight* of the body, but as there is no motion, no work is done. If the body is lifted, work is done *against* the attraction of the earth; if it is allowed to descend, work is done *by* the same force. The displacement must be partly at least in the line of action of the force. Thus, if the body is moved horizontally no work is done.

Force is measured either by comparison with the earth's attraction on a standard body, as a pound or kilogram; or else by the rate at which it will change the motion of a body. The latter method, called the

absolute method as it is independent of location, is preferable for scientific purposes. When the centimeter, gram, and second are adopted as units of length, mass, and time—a convention which is at the basis of nearly all scientific measurements and especially of electrical measurements—the absolute unit of force is called the *dyne*. It is defined as that force which will change the velocity of a gram mass by one centimeter per second during each second that it acts upon it. This unit is quite small, being equal to the weight of the 980th part of a gram.

Work is measured by the product of the force and the displacement in its direction. The unit of work corresponding to the dyne is called the *erg*, which is the work done by a dyne acting through a centimeter. As this unit is very small, a large unit equal to ten million ergs is frequently used, especially as a practical unit of electrical work. This unit is called the *joule*.[1]

It is often desirable to express the *rate* at which work is done. Thus, a large machine will do a given amount of work in less time than a small one. The rate of doing work is called *power* or *activity*. The practical unit of power is called the *watt*,[2] which is equivalent to one joule per second. The power of a machine in watts is given by dividing the work done by the time taken to do it; or, in symbols—

$$P = \frac{W}{t}$$

where W represents the number of joules and t the number of seconds. Conversely, if the power is multiplied by the time, the amount of work is obtained. For this reason a joule is sometimes called a watt-second; and a larger unit called a watt-hour, which is equal to 3600 joules, is frequently used.

Energy.—When a body is capable of doing work it is said to possess *energy*, the amount of energy being measured by the work it can do. This energy may be due to its position, in which case it is called *potential* energy, or to its motion, when it is called *kinetic* energy. A raised weight or a coiled spring possesses potential energy, a moving rifle bullet kinetic energy. As a body does work it loses its energy. On the other hand, in order that a body shall gain energy, work must be done upon it.

It is one of the greatest generalizations of science that while energy may be transferred from one body to another, or from one form to another, it cannot be created or destroyed. The total amount of energy in any isolated system is always the same. Apparent gains or losses are accounted for by the inclusion of other forms of energy, as heat, chemical energy, etc., which have been shown to be equivalent to

[1] From the English investigator James Prescott Joule. The practical English unit is the *foot-pound*, which is equal to 1.36 joules.

[2] From James Watt, to whom we owe the development of the steam engine. A multiple of this, the *kilowatt*, equal to 1000 watts, is often used. A common English unit of power is the *horse-power*, which is 550 foot-pounds per second, and which is nearly equal to 746 watts, or about three-fourths of a kilowatt.

mechanical energy. This is the principle of the Conservation of Energy, which lies at the basis of modern science.

Units of Electricity.—In estimating the quantity of electrical charge it is necessary to adopt some unit as a standard of comparison. There are two methods by which this is done. In the first the unit charge is determined by the amount of attraction or repulsion it will exert, and is known as the *electrostatic unit charge.* It is defined as the charge which will repel an equal charge across a centimeter of air with unit force, *i. e.*, with a force of one dyne (p. 23). The second method is based upon the magnetic effects of the electric current which are to be described later (p. 66). The unit charge almost universally used in practice is defined by this method and is known as the *coulomb.*[1] It is much larger than the other unit, one coulomb being equal to three thousand million (3×10^9) electrostatic units.[2]

As an indication of the minuteness of the electron it may be added that there are about the same number (3×10^9) of electrons in one electrostatic unit; so that one coulomb contains nine trillions (9×10^{18}) of electrons; so great a number that a little more than half of them would be sufficient, if placed a centimeter from one another, to cover the entire surface of the globe.

ELECTRICAL POTENTIAL

The Electrical Field.—The space surrounding an electrified body, through which its influence extends, is called an *electrical field of force.* The character of an electrical field depends upon the amount and distribution of the charges present. If a small[3] positively charged body is placed at any point in an electrical field, a force proportional to its charge acts upon it, urging it in a definite direction. An equal negative charge will experience a force of the same amount, but in the opposite direction. The direction of the force on the positive charge is called the direction of the field at that point, and the intensity of the field is measured by the ratio of the force to the charge.

An electric field may be represented by drawing lines which at each point have the direction of the field. Such lines are called lines of force. By the usual convention their number is made proportional to the strength of the field. They start from positive charges and end on negative ones. Thus, the field of force due to a single charge would be

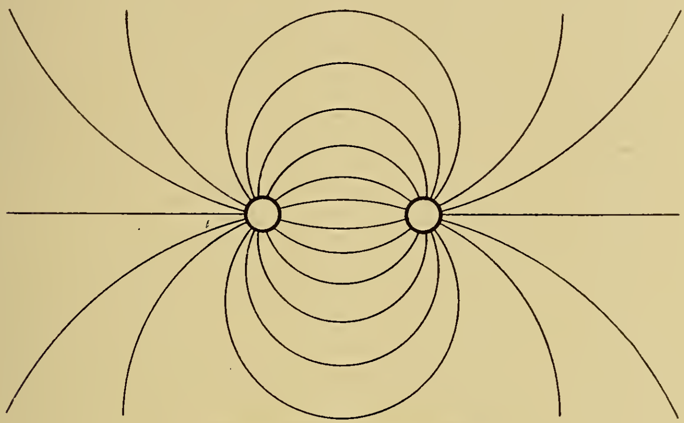
[1] From Charles Auguste Coulomb, a French physicist, who investigated the laws of electrical attraction and repulsion. For the definition of the coulomb see note, p. 42, and note 1, p. 67.

[2] Multiples and submultiples of the coulomb (as of all electrical units) are named by using the same prefixes as in the metric system. Thus a kilocoulomb is 1000 coulombs, a centicoulomb is 0.01 coulomb, a millicoulomb 0.001 coulomb, etc. In addition, the prefixes *mega-* and *micro-* are often used to denote a million and a millionth respectively. Very large and very small numbers are often more briefly expressed by writing their significant figures multiplied by the proper power of 10. Thus, 3,000,000,000 $= 3 \times 10^9$, 0.000004 $= 4 \times 10^{-6}$, etc.

[3] Small, so as not to disturb the distribution of charges in the field.

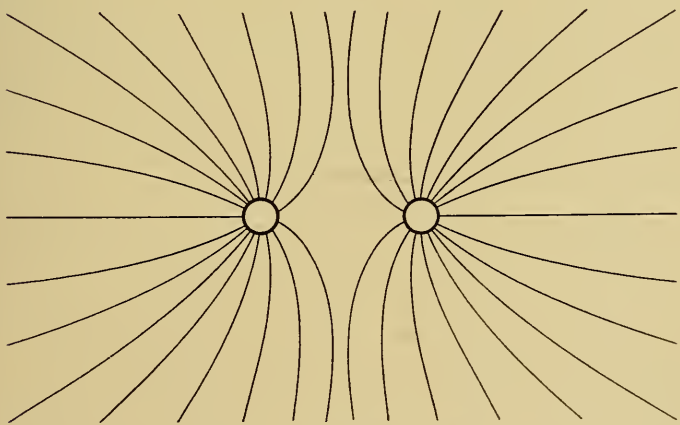
represented by radial lines, drawn outward if the charge is positive and inward if it is negative. If there are several charges in the field, the direction of the force at any point is the resultant of the effects of all the charges. The lines of force in general become curved. Thus the field due to two equal unlike charges is given by Fig. 3, and that due to two equal like charges by Fig. 4.

FIG. 3



Field of two equal unlike charges.

FIG. 4



Field of two equal like charges.

It must be understood that these lines of force have no real existence, but merely serve as a convenient means of indicating the character of the field. In the development of electrical theory by Faraday and Maxwell it is shown that they represent stresses in the ether, and that all forces on electrified bodies may be explained by supposing that the

ether exerts a tension along the lines of force and a pressure perpendicular to them; as if they tended to contract and to repel each other. Thus a glance at Figs. 3 and 4 will show how on this interpretation two unlike charges are drawn together while like charges are driven apart.

Energy of the Field; Potential.—Every electrical field possesses an amount of energy which is equivalent to the work done in separating the charges and placing them in position against the electrical forces. This energy is of the form known as energy of position, or potential energy (p. 23). An analogy which may be of assistance in the study of these phenomena is found in the gravitational field of the earth. Thus a quantity of water in an elevated reservoir possesses potential energy due to its position above the earth's surface. This energy is equal to the work necessary to raise it, and the water may be made to do an equal amount of work in its descent. Likewise the energy of electrical separation may be made to produce an equivalent amount of work.

If a small test charge is moved about in an electrical field it is clear that the amount of work done, and therefore the potential energy of the charge, will vary with its position. If free, the charge will move so as to diminish its potential energy, just as a weight tends to descend toward the earth. All points at which the test charge has the same potential energy are said to be at the same *potential*, and (when the charge is positive) points at which the energy is greater or less are said to be at higher or lower potential respectively.

This term *potential* is one of the most important terms in electrical science, and it is essential that a clear view of its meaning should be obtained. As has been seen, it is derived from the conception of potential energy, and is measured by the potential energy of a test charge. It is the property of the field which corresponds to *level;* the property which determines the tendency of electricity to move from place to place. If two points are at different potentials, a free positive charge will move from that of higher to that of lower potential, while a negative charge will of course move in the opposite direction.

If two points at different potentials are connected by a conductor, a charge will pass through the conductor. It follows, therefore, that if electricity is at rest on a conductor, all parts must be at the same potential. It must be understood that the potential of a conductor is due to its own charge as well as to any other charges in the field. Thus, the potential of a positively charged conductor is higher than if it were uncharged, because more work must be done in bringing a positive charge up to it.

The conception of potential must be carefully distinguished from that of charge. The distinction may be made clearer by comparison with the analogous case of the gravitational field already alluded to. If two reservoirs of water are connected by a pipe, the flow is determined not by the quantities of water in the reservoirs, but by the difference of level. If their surfaces are at the same level no flow will take place. In a similar manner, when two charged bodies are connected by a

conductor, it is not the relative size of the charges, but the difference of potential which determines the direction of the transfer of electricity.

Zero of Potential.—Just as in the measurement of water levels a standard datum of reference—usually the mean sea level—is chosen, so electrical potential is measured by reference to some standard. It is customary to assume the earth to be at zero potential; all bodies at a higher potential than the earth thus being positive, and those lower being negative.[1] While this is usually a convenient assumption, it is sometimes necessary to take into account the fact that the potential of the earth varies both with time and place.

Electromotive Force.—The difference of potential between two points, which determines the tendency of a charge to move from one to the other, is often called the *electromotive force*, or, as it is commonly written, the *E. M. F.* between the points. This term is somewhat misleading, as the electromotive force does not represent a force, but a quantity of work. It is, however, a convenient expression and has been universally adopted. It is to be understood as equivalent to the expression difference of potential.[2]

Units of Potential.—As the potential at a point is determined by the energy of the test charge, it is natural to measure it by the energy of a unit charge, or by the work done in bringing unit charge to that point from a point of zero potential.[3] The unit of potential difference is therefore that which exists between two points when unit work is done in carrying a unit charge from one point to the other. The practical unit of potential difference or E. M. F. between two points is that which requires the expenditure of a joule of work (p. 23) to carry a coulomb between the points. This unit is called the *volt*.[4] In the electrostatic system the unit of work is the erg. The electrostatic unit of potential difference is therefore that which exists between two points when an erg of work is necessary to carry an electrostatic unit charge from the lower to the higher. As the coulomb is equal to 3×10^9 electrostatic units of charge (p. 24) and the joule is 10^7 ergs, it may readily be calculated that a volt is equal to $\frac{10,000,000}{3,000,000,000}$, *i. e.*, to $\frac{1}{300}$ of an electrostatic unit.

ELECTRICAL CAPACITY

Capacity.—As a body is charged (with positive electricity) its potential rises, since the greater the charge already on the body, the more work must be done to bring up an additional charge. This increase continues until the potential becomes so high that the tendency of the charge to escape overcomes the insulation, and there is either a steady

[1] Connecting a conductor to the earth, or "grounding it," is the same as bringing it to zero potential.

[2] Frequently the term "voltage" is used as an equivalent expression.

[3] Provided that the unit charge produces no disturbance of the field. See note 3, p. 24. Otherwise a smaller charge is taken and the potential is measured by the ratio of the work to the charge.

[4] From Alessandro Volta, the discoverer of contact potential difference.

leakage or a sudden discharge in the form of a spark. The potential at which this will occur depends on a number of factors, such as the insulating properties of the supports, the condition of the air, the rate of charge, etc.; it is therefore impracticable to determine the total charge that a body will hold. The term *capacity* is therefore used with a somewhat different meaning. The capacity of a conductor is defined as the quantity of charge which will raise its potential from zero to unity. It depends upon the size and shape of the conductor and also, as will be seen later, upon its surroundings.

As a double charge will produce double repulsion, it is evident that the potential increases in proportion to the charge. Therefore, if Q be the charge, E the potential, and C the capacity of a conductor, the relation between them is given by the formula

$$Q = C E.$$

Units of Capacity.—The practical unit of capacity is called the *farad.* It is the capacity of a conductor which will be raised to a potential of one volt by a charge of one coulomb. As this unit is inconveniently large, it is customary to employ as a subsidiary unit the microfarad, which is one millionth of a farad. In the electrostatic system the unit capacity is defined similarly in terms of the units of that system. Since one coulomb is 3×10^9 electrostatic units of charge and one volt is $\frac{1}{300}$ electrostatic unit of potential, one farad must be equal to 9×10^{11} electrostatic units of capacity, and a microfarad 9×10^5, or 900,000 of these units.

As an illustration of the use of the practical units let us calculate the potential of a conductor of 20 microfarads' capacity containing a charge of 0.005 coulomb. From the relation above we have

$$E = \frac{Q}{C},$$

therefore

$$E = \frac{0.005 \text{ (coulombs)}}{0.000020 \text{ (farads)}} = 250 \text{ volts.}$$

Electrostatic Energy.—Since the work done in displacing a charge is clearly proportional to the charge, it follows from the definition of the unit of potential (p. 27) that this work is equal to the product of the charge by its increase of potential. If Q represents the amount of the charge and E the difference of potential, the work is

$$W = Q E.$$

Thus if 600 coulombs are transferred from a point of potential 2 to one of potential 10, the work done is 600×8 or 4800 joules. If the product is positive, it represents the increase in the energy of the charge and must be supplied from some external source. If it is negative, the charge loses energy, and this energy will appear in some other form. For instance, if the transfer takes place along a wire, the wire is heated.

The energy of a conductor charged with a quantity Q and having a potential E is not $Q E$ but $\frac{1}{2} Q E$. For if we consider the work in charging

it to be divided into a number of small steps by bringing up successively small portions of the charge, we see that for the first step the potential was zero (the conductor being uncharged), while for the last step the potential was E. The average was therefore $\frac{1}{2}E$, and consequently the work done in charging the conductor was

$$W = \tfrac{1}{2} Q E$$

Moreover, since $Q = CE$, we may also express the work in terms of the capacity and either the charge or potential, thus:

$$W = \tfrac{1}{2} C E \times E = \tfrac{1}{2} C E^2$$

and

$$W = \tfrac{1}{2} Q \times \frac{Q}{C} = \tfrac{1}{2} \frac{Q^2}{C}.$$

Thus, to raise a conductor of 20 microfarads' capacity to a potential of 200 volts requires the expenditure of $\frac{1}{2} \times 0.000020 \times 200^2 = 0.4$ joules, while to give the same conductor a charge of 0.005 coulombs (5 millicoulombs) would take $\frac{1}{2} \frac{(0.005)^2}{0.000020} = 0.625$ joules.

It should be noticed that while the work to charge a conductor to a given *potential* is directly proportional to the capacity, the work to put a given *charge* on it is less as its capacity is greater. For instance, if two conductors, one having twice the capacity of the other, are raised to the same potential, the charge given to the larger will be double that of the other; and as the potential is the same, twice as much work will be used in charging the larger. But if the two conductors are given the same charge, the smaller will be raised to twice the potential of the larger, and therefore, in this case, the work of charging the smaller will be double. A charged conductor is, in fact, exactly analogous to a bent spring, the capacity corresponding to the flexibility of the spring, while the charge and potential are represented by the displacement and tension of the spring respectively. The more flexible the spring, the greater must be the displacement to produce a given tension, and the greater the work done in producing it. But to produce a given displacement, the less work is done as the spring is more flexible.

Summary of Electrical Quantities.—A summary of the quantities so far considered is given in the following table, which gives the symbols by which they are usually denoted, the formulas showing the relation between them, the names of the practical units, and the number of electrostatic units in one practical unit:

Quantity.	Symbol.	Formula.	Practical unit.	No. e. s. units in 1 practical unit.
Work or energy . .	W		Joule	10^7
Power	P	P = W/t	Watt	10^7
Charge	Q		Coulomb	3×10^9
Potential or E. M. F.	E	E = W/Q	Volt	$\frac{1}{300}$
Capacity	C	C = Q/E	Farad	9×10^{11}

ELECTROSTATIC INDUCTION

Electrification by Induction.—When a conductor is placed in an electrical field, it becomes charged even though uncharged before and though not brought into contact with any charged conductor. This phenomenon is known as *electrostatic induction.* Thus, if an insulated conductor is brought near a positively charged body, the part nearest the body becomes negatively charged and that farthest from the body positively (Fig. 5); moreover, the quantities of the positive and negative charges are exactly equal. The stronger the field in which the body is placed, the greater is the amount of the induced charge.

Fig. 5

Electrification by induction.

When the conductor is removed from the field, the charges unite and all signs of electrification disappear. However, the opposite charges may be permanently separated if the conductor, after being placed in the field, can be divided into two parts insulated from each other. Or in some cases, if it is connected to the earth the charge of one kind will disappear, thus leaving the body permanently electrified. For instance, in the example given above (Fig. 5), if the conductor, after being placed near the inducing charge, is momentarily connected to the earth, the positive charge will escape and the body will remain negatively charged.

The explanation of the phenomenon of induction on the fluid theory is very simple. The effect of the field is to produce electrical separation, drawing the positive and negative charges in opposite directions. Whether both kinds of electricity are free to move or, as in the electron theory, only the negative charge is displaced, the result is the same. The conductor becomes oppositely charged at its ends, the positive charge appearing at the end which was at a lower potential, and the process continues until the tendency of the induced charges to unite again is great enough to counterbalance the effect of the external field. The potential is then uniform throughout the conductor.

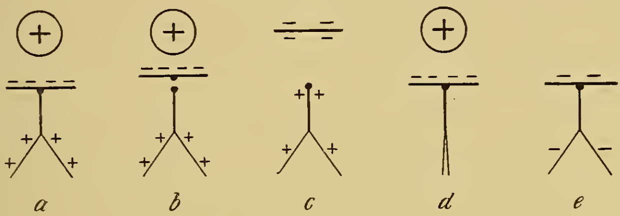
It necessarily follows from this theory that in every case of induction equal amounts of the two charges are produced; and this, in fact, is found to be true. Even in the case where the conductor is connected to the earth the charges are equal, though one is so widely distributed that it is practically lost.

The phenomena of electrostatic induction may be illustrated with a gold leaf electroscope. If, for example, a positively electrified glass rod is brought near the plate of an electroscope, the negative charge is drawn to the plate while the positive is repelled to the leaves, causing

them to diverge (Fig. 6, *a*). Removal of the glass rod results in the charges uniting again, leaving no trace of electrification.

If the plate is detached from the electroscope and removed by an insulated handle while the glass rod is still present, it is found to be negatively charged, while the electroscope itself is charged positively (Fig. 6, *b* and *c*). If, instead of detaching the plate, we connect it to the earth by touching it for a moment, the positive charge escapes, causing the leaves to collapse, while the negative is still bound to the plate by the attraction of the charge on the rod (Fig. 6, *d*). On now removing the rod, the leaves diverge again, since the negative charge spreads over the whole instrument (Fig. 6, *e*).

Fig. 6



Charging an electroscope by induction.

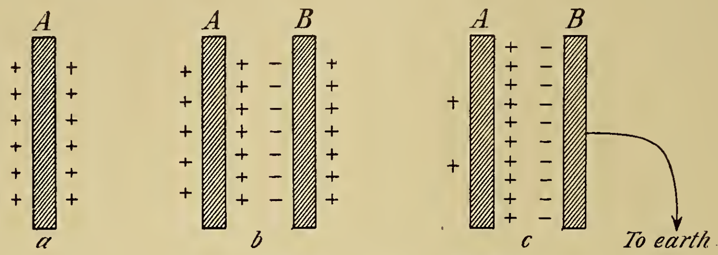
The gold leaf electroscope gives a ready means of detecting the sign of a charge. When it is charged with electricity of known sign, the approach of a charged body to the plate produces a greater divergence of the leaves if its charge is of the same sign as that on the electroscope, since the charge induced on the leaves is of the same sign as that already present. On the other hand, an oppositely charged body causes the leaves at first to fall together, though afterward, if the charge is great enough, after a complete collapse they may diverge again on its closer approach.

Effect of Induction on Capacity.—The phenomena of induction greatly modify the distribution of charge and the capacity of conductors. Thus, the charge on an isolated conducting plate is equally distributed on the two sides (Fig. 7, *a*); but if a second uncharged plate is brought near, so that induction takes place, the reciprocal action of the induced charge will cause a greater density of charge on the side of the first plate turned toward the other. While the second plate is insulated, the effect is partially neutralized, because the two kinds of charge on this plate have opposite effects and the net result is only the difference between the two (Fig. 7, *b*). But if one kind is allowed to escape by making connection with the earth or with a source of the opposite kind of charge, the charges of both plates are largely confined to the sides facing each other (Fig. 7, *c*).

The presence of the second conductor, especially if grounded, lowers the potential of the charged conductor. For example, in Fig. 7, *c*, if a

positive charge is brought up to the plate A, the repulsion of the charge already on A is largely counterbalanced by the attraction of the negative charge of B, consequently the work done and therefore the potential of A is less than if B were not present. It follows that a larger charge will be required to raise the potential of A by a given amount: in other words, that its *capacity* (p. 28) is increased by the proximity of the conductor B.

Fig. 7

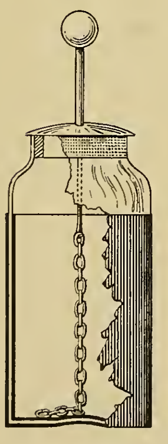


Mutual action of induced charges.

This effect of increasing the capacity is very marked, especially if the distance between the conductors is made small. Thus, the capacity of a single circular plate one meter in radius is about 0.00007 microfarad; but if placed one millimeter from a similar plate which is connected to the earth, its capacity is increased to 0.028 microfarad, or is 400 times as great as before.

The Condenser.—A device of this kind, by which the capacity of a body is increased, is called a *condenser*. It consists essentially of two conductors separated by a thin sheet of insulating material. The capacity is directly proportional to the area of the conductors and inversely to the distance between them. A familiar form of condenser is that known as the Leyden jar (Fig. 8). This is constructed by coating with tinfoil the inside and outside surfaces of a wide-mouthed glass jar. The upper part is left uncoated so that the conductors will be insulated from each other, and an insulated rod passing through the lid serves to make connection with the inside. An ordinary Leyden jar of the gallon size has a capacity of two or three thousandths of a microfarad, and is equivalent to a single spherical conductor one or two miles in radius.

Fig. 8



Leyden jar.

Another form of condenser is used when a larger capacity is desired. It is composed of a number of sheets of tinfoil separated from each other by somewhat larger layers of an insulator, such as mica or paper soaked in paraffin. The alternate sheets of tinfoil are connected together, thus forming the two conductors. The arrangement of plates is shown in Fig. 9, where the heavy lines represent the

tinfoil sheets and the lighter ones the insulating layers. The whole is enclosed in an insulated case for protection and is provided with binding posts for making connections. A condenser of this type is shown in Fig. 10. This really consists of ten separate condensers, each of one microfarad capacity, and ten having each one-tenth microfarad capacity. One side of each condenser is connected to one binding post, while

Fig. 9

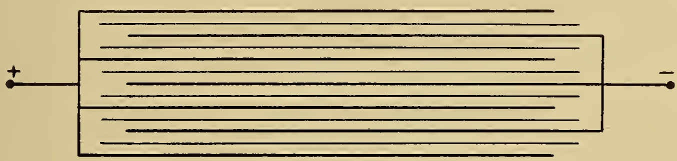
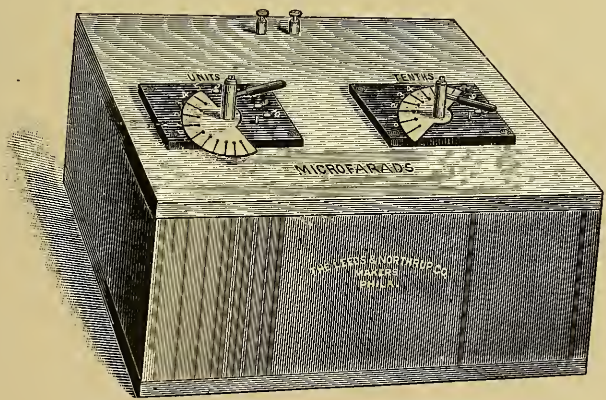


Plate condenser.

the other side connects with one of a series of knobs, which can be successively connected with the second binding post by turning a switch. The whole condenser is contained in a box about a foot square; a single conductor of this size would have only about one-millionth of the capacity.

This type of condenser cannot be charged to very high potential, as the insulating sheets between the plates are so thin that they might be perforated if the strain was great. When high potentials are used,

Fig. 10



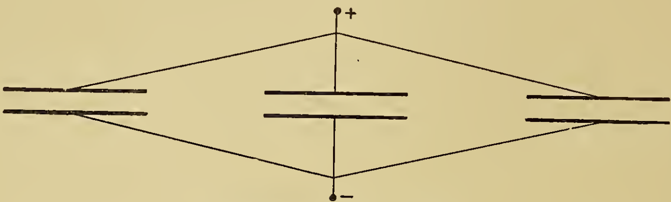
Adjustable condenser.

condensers are often constructed by immersing metal plates, connected alternately as above, in an oil of high insulating power. One advantage of the oil over a solid insulator lies in the fact that an accidental discharge through it does not permanently destroy the condenser.

Combinations of Condensers.—There are two ways in which condensers may be combined. In the first method the corresponding terminals

of all the condensers are joined together, as in Fig. 11.[1] This is called connecting in parallel or in multiple, and is used when a large capacity is desired. It is evident that in this form of combination, all the condensers are raised to the same potential, while the total charge is the sum of the charges on the separate condensers. We therefore have the rule: *When condensers are connected in parallel the capacity is equal to the sum of the capacities of the separate condensers.* In particular, the capacity of n similar condensers in parallel is n times that of one.

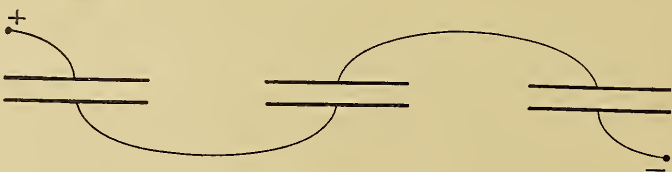
Fig. 11



Condensers connected in parallel.

The other method of combination is known as the series or cascade arrangement. The condensers are connected as shown in Fig. 12. When a charge is placed on the first condenser (the last being grounded) all the others will become equally charged by induction. As the total difference of potential between the first and last is the sum of the individual potential differences, and as the charge given at the terminal is the same as when only one condenser is used, it follows that the capacity is less than that of any one of the condensers. It may be shown that

Fig. 12



Condensers connected in series.

when condensers are connected in series the reciprocal of the capacity is equal to the sum of the reciprocals of the capacities of the separate condensers. In particular, the capacity of n similar condensers in series is one nth of that of one. Since the total potential difference is distributed among the condensers, this arrangement is useful when very high potentials are used.

Specific Inductive Capacity.—The capacity of a condenser depends not only upon its dimensions as indicated above, but also upon the

[1] Two equal parallel lines are used conventionally as a symbol for a condenser.

medium between the plates. Thus, if the space between the plates is filled with turpentine instead of air, the capacity is more than doubled; if sulphur is used, it is nearly four times as great, and so on. This property of the insulating medium is known as its *specific inductive capacity,* or *dielectric constant.* The ratio of the specific inductive capacity of a few substances to that of air, as measured by the comparative capacities of similar condensers, is given in the following table.

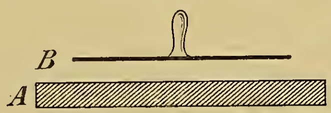
Turpentine	2.2
Paraffin	2.3
Glass	6 to 10
Mica	6.6
Sulphur	3.8

ELECTRICAL MACHINES

Frictional Machines.—An apparatus for the continuous production of electrical charges is called an electrical machine or a static machine. The older type of electrical machine generated the charges by friction. An insulator such as a glass plate or cylinder was mounted on an axis and continuously rubbed by being rotated while in contact with a cushion of silk or other suitable material. At the best these machines were very inefficient, and they have been entirely superseded by machines acting on the principle of induction.

The Electrophorus.—The simplest induction machine is known as the electrophorus. It consists of a base of hard rubber (Fig. 13, *A*) on which rests a metallic plate, *B*, provided with an insulating handle. If *A* is negatively electrified and then *B* put in place, a positive charge will be induced on the under side of the latter and a negative one on the top. Since *A* is an insulator, its charge does not escape to *B* except at the comparatively few points where the plates are in actual contact. Touching *B* with the finger removes the negative charge, while the positive

FIG. 13



Electrophorus.

is held bound by the attraction of the charge on *A*. On removing the plate *B*, its charge becomes free, while *A* is practically in the same condition as before. After discharging *B*, the process may be repeated a large number of times.

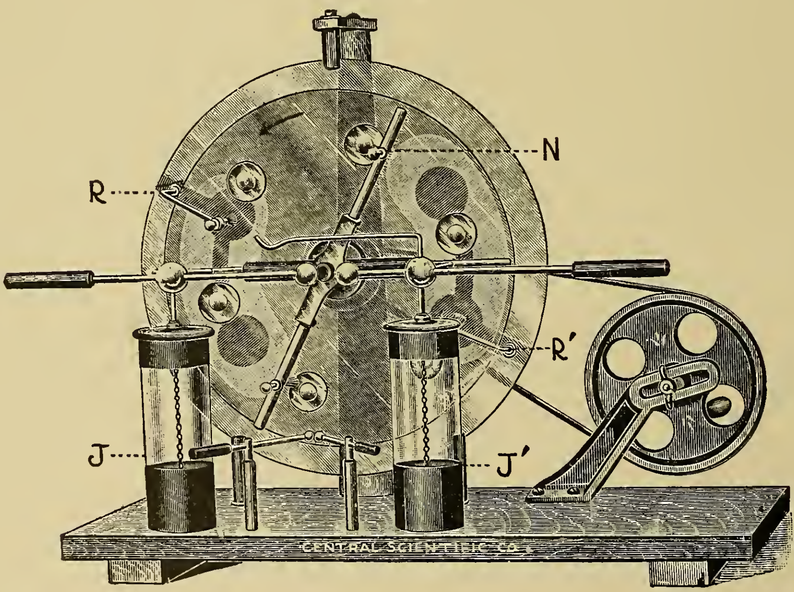
It must not be thought that this continuous production of electrification from a single charge is a violation of the principle of the conservation of energy. What is accomplished is not the creation of a charge, but the separation of two opposite charges, as the total negative

charge which escapes to the earth is exactly equal to the positive charge produced upon the plate. It is true that the charges when separated possess a greater amount of potential energy; but this energy is exactly equivalent to the excess of work done in removing the positively charged plate against the attraction of the negative charge on A.

The Induction Machine.—The induction machine is practically a continuous electrophorus. It consists of two essential elements called *inductors* and *carriers*, corresponding to the plates A and B respectively, as well as a means of collecting the charges generated. The relative motion of the inductors and carriers is produced by rotation, and the necessary contacts are made by small tinsel brushes touching the carriers at the proper times. In order to work continuously the machine must also be arranged so that the inducing charges will be replenished as they are lost by leakage.

Two types of machine in most frequent use are the Töpler-Holtz or Voss machine, and the Wimshurst machine.

Fig. 14



Töpler-Holtz Machine.

The Töpler-Holtz Machine.—This machine is represented in Fig. 14. A glass plate, coated with shellac to increase its insulating power, carries six equidistant tinfoil disks or carriers. This rotates in front of the inductors, which are of paper and tinfoil of the form indicated in the figure, mounted on a slightly larger stationary glass plate. There are three pairs of contact brushes. One pair attached to a diagonal bar (N) serve to bring two opposite carriers into connection just before they

leave the influence of the respective inductors. These may be called the neutralizing brushes. The second pair, R, R', one metallically connected to each of the inductors, touch the carriers just as they come opposite the latter; these may be designated the replenishing brushes. The third pair, the collecting brushes, one directly opposite to each inductor, are joined to the terminals of the machine. The capacity of the apparatus is increased by connecting the terminals to the inside coatings of two small Leyden jars, J, J', the outside coatings of which are connected to each other.

Fig. 15 gives a diagram of the essential parts, arranged for clearness in a straight line instead of a circle. Here A is the fixed plate carrying the inductors I, I'. B is the revolving plate with the carriers in various positions. N is the neutralizing bar with a contact brush at each end, R, R' the replenishing brushes, one connected to each inductor, and C, C' the collecting brushes joined to the terminals T, T'. J, J' indicate the two jars connected in series.

FIG. 15

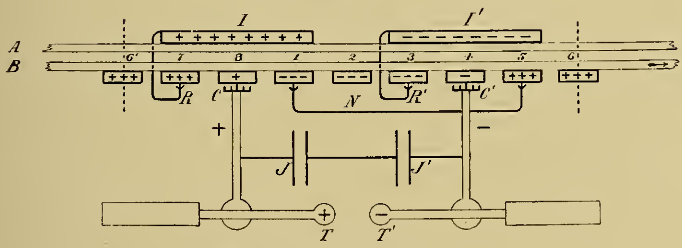


Diagram of action of Holtz machine.

The simplest way to understand the action of the machine is perhaps to regard each pair of carriers as the plates of a double electrophorus. Consider two opposite carriers in the positions 1 and 5, just about to leave the inductors I, I', which may be assumed to contain respectively a positive and a negative charge. The carriers are charged by induction, and at this moment they are connected by touching the neutralizing brushes on the bar N. The positive charge repelled from 1 and the negative charge from 5 neutralize each other, leaving 1 with a negative charge bound by the attraction of the inductor I, and 5 with a positive charge similarly bound. As the carriers leave the inductors, these charges become free, as in positions 2 and 6. (Notice that in the figure, 6 and 6′ represent the same position.) On arriving at position 3, opposite the negative inductor, the negatively charged carrier touches the replenishing brush R', and gives up part of its charge to the negative inductor I', unless this is already fully charged. In this way the charge on the inductor is built up, and any loss due to leakage is made good. The carrier then moves on to position 4, where it gives up the remainder of its charge to the collecting brush C'. In the

meantime the other carrier has replenished the positive inductor in the same way, and contributed its charge to C.

The carriers now move on into positions 5 and 1 respectively, completing half a revolution; each has now taken the place of the other, and during the remainder of the revolution the action is similar. Each carrier contributes its share, and the terminals of the machine with the attached jars are oppositely charged until the difference of potential is great enough for a spark to pass. The greater the capacity of the condensers, the fewer will be the sparks and the greater the intensity of each spark, while if no condensers are used, there will be an almost continuous brush discharge.

In the description of the action of the machine given above it was assumed that the inductors initially contained opposite charges. It is not necessary, however, to charge these from a separate source, for a small charge is always present, due to the contact of dissimilar substances, or remaining from a previous operation of the machine. And as at every revolution this charge is increased by each carrier as it touches the replenishing brushes, the inductors soon attain their full charge. The machine is therefore said to be self-exciting.

The efficiency is increased by adding to the brushes a number of sharp points turned toward the revolving glass plate. These perform the same function for the plate that the brushes do for the carriers, any charge induced on the plate drawing an opposite charge to the points; and as these are unable to retain the charge, it escapes to the plates. The effect is the same as if the charge on the plate had been drawn off by the points.

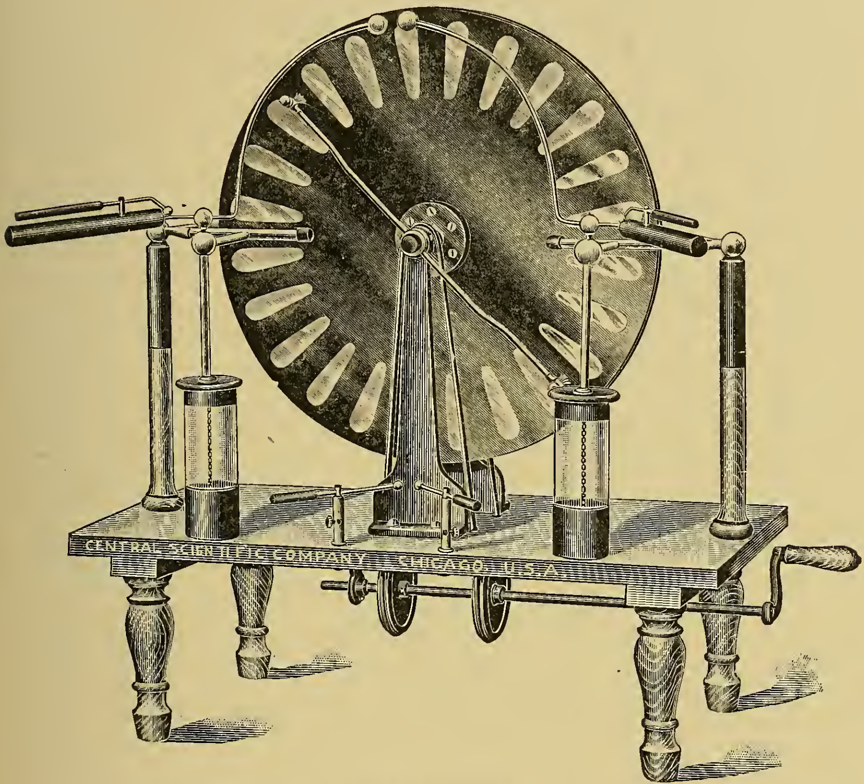
The Wimshurst Machine.—This machine, which is represented in Fig. 16, is somewhat simpler in construction. Two similar glass or ebonite plates, each carrying a number of metallic sectors, are mounted so as to rotate in opposite directions. These sectors serve both as carriers and inductors. A neutralizing arm with brushes is provided for each plate, the two being at right angles to each other and at forty-five degrees to the collecting brushes, which are mounted on forks encompassing both plates. Terminal knobs and condensers are arranged as before. The direction of the rotation of the plates should be such that a sector, after leaving the collecting brushes, touches its own neutralizing brush before coming opposite that of the other plate. Thus, in the machine shown in the figure, the front plate should revolve in the direction of the hands of a clock.

A diagram of the essential parts is shown in Fig. 17. Here again, as in Fig. 15, the parts are arranged in a straight line. A and B are the revolving plates carrying the tinfoil sectors in opposite directions. N_1, N_2 are the neutralizing bars with brushes, connecting opposite sectors. C, C' are the collecting brushes, which are double. The other letters have the same meaning as in Fig. 15.

The action is as follows: Suppose that a sector on the back plate arrives at position 1 with a small positive charge. The front sector

opposite, in contact with the neutralizing bar N_1, will be charged negatively by induction, while sector 5, at the other end of the bar, will

Fig. 16



Wimshurst machine.

Fig. 17

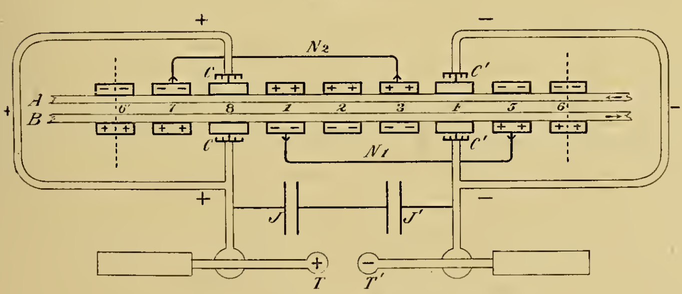


Diagram of action of Wimshurst machine.

receive a positive charge. As the plate revolves, the front sectors move forward, carrying their charges, into positions 3 and 7 respectively, opposite the rear neutralizing bar N_2. They now act as inductors upon

the adjacent sectors of the rear plate, charging these oppositely, and then pass on to positions 4 and 8, where they give up most of their charges to the collectors C' and C. C' thus receives a negative charge and C a positive one.

In the same way the carrier on the rear plate, which has been charged positively when in position 3, moves in the opposite direction to position 1, where it acts inductively upon the front plate as before described, and then carries its positive charge to the collector C. It is thus seen that this collector receives a positive charge from the carriers of both plates. Similar consideration of the other sectors shows that C' receives a negative charge from each plate. To sum up, each sector first is charged by induction, then itself induces a charge upon a sector on the other plate, and finally gives up its charge to the proper collector.

The charges originally on the sectors may be quite small. As in the Holtz machine, they are built up by the operation of the machine. Thus, if a front sector arrives in position 1 with a residual positive charge, this will be repelled to sector 5 and increase its charge. Therefore this machine also is self-exciting.

Working Conditions.—The efficiency of a static machine depends upon the insulation, and this is largely dependent upon the state of the atmosphere. In damp weather the plates are apt to be coated with moisture, through which the charge escapes. The insulation is also impaired by dust upon the plates. It is well, therefore, to protect the machine by a case, the air being kept dry by some substance which absorbs moisture. Recently an increased efficiency has been obtained by enclosing the machine in an air-tight case and raising the pressure of the air, since the insulating properties of air are greater at higher pressures. In another recent type, the carriers are embedded in a revolving plate of vulcanite with the exception of small buttons by which contact is made with the brushes (see also p. 207).

The difference of potential which it is possible to produce with a static machine depends upon its size, for after a certain point the opposite charges will leak across the plates and neutralize each other. This difference of potential is measured by the maximum length of spark that the machine will give (see p. 51). With a large machine it may amount to 200,000 to 300,000 volts. Increased rate of generation of charge is obtained by more rapid rotation, and by increasing the number of plates, all the collecting brushes being connected to one pair of terminals. This is equivalent to connecting a number of machines in parallel. While the potential is not increased, the rate at which the charge is generated is increased in proportion to the number of the plates. Even when many plates are used, however, the quantity of charge is not very great; with a large machine it would take perhaps five minutes to generate one coulomb. An electrical machine, therefore, is a device for raising a small quantity of charge to a high potential. Other electrical generators will be considered later (pp. 53 and 81) in which the quantity is much greater but the potential is less.

CHAPTER II

THE ELECTRIC CURRENT

THE CURRENT

Production of a Current.—If two bodies which are at different potentials are connected by a conductor, the potential will tend to become equalized by the transfer of an electric charge along the conductor (p. 26). Thus, if the two plates of a charged condenser are connected by a wire, the opposite charges unite, neutralizing each other, and the plates are brought to the same potential. Such a transfer of charge is called an electric current. In the example given the current will be of very brief duration; but if by some means the difference of potential between the ends of the wire is maintained, a continuous current will be produced.

It is evident, therefore, that an essential requisite to the production of a continuous current is some device for the maintenance of a difference of potential. Such a device is called an electric generator. One form of generator, which has already been described (p. 36), is the static electrical machine. As the currents to be obtained from even the largest machine are very small, other forms of generator are used for the production of larger currents. These forms will be described later (pp. 53 and 81).

Direction of the Current.—Since equal quantities of positive and negative charge neutralize each other, the transfer of a positive charge in one direction is exactly equivalent to the transfer of an equal negative charge in the opposite direction. The effect is the same whether the current is produced by the motion of positive or negative electricity or partly by one and partly by the other. In any case, it is generally agreed to take as the direction of the current that of the transfer of the *positive* charge. The current is therefore supposed to flow from the point of the higher to that of lower potential. By this convention the analogy between the flow of electricity and that of water (p. 26) becomes closer; for whenever by a device, such as a pump, a difference of level or pressure is maintained between two reservoirs of water connected by a pipe, a current of water flows from the higher to the lower.

Unit of Current.—Just as a current of water is measured by the rate at which the water is transferred, for instance, in gallons per second, so the strength or intensity of an electric current may be measured by the quantity of positive charge transferred per second. The electrostatic unit current would therefore be produced by the transfer of one electro-

static unit charge per second; but this unit is seldom used. The practical unit of current is a current of one coulomb (p. 24) per second, and is known as the *ampere*.[1]

In general, if we denote by i the intensity of a current, and by t the time, we have

$$i = \frac{Q}{t},$$

Q being the total transfer of positive charge. For example, if an electrical machine generates a positive charge of 18 coulombs per hour, the current between the terminals would be $\frac{18}{3600}$ ampere, *i. e.*, 0.005 ampere or 5 milliamperes. (This is approximately the magnitude of the greatest current which can be drawn from a large static machine.) Instruments for measuring the intensity of a current will be described later (p. 70).

ELECTRICAL RESISTANCE

Electrical Resistance; Ohm's Law.—The intensity of a current flowing through a conductor depends not only upon the difference of potential or E. M. F. between its ends, but also upon the nature of the conductor. Thus, if the same E. M. F. be applied to similar wires of copper and iron, the current in the copper will be much greater than that in the iron. For a given conductor there is found to be a constant ratio between the E. M. F. and the current which it produces, the value of this ratio depending on the size, material, and temperature of the conductor. On account of its analogy with the frictional resistance of a pipe to the flow of water, this ratio is called the *resistance* of the conductor, since the greater the resistance, the larger an E. M. F. is needed to produce a given current.

This law, which is known as Ohm's Law, from the discoverer,[2] is of fundamental importance in electrical science. It has been abundantly tested and found to hold with the greatest accuracy for all currents in solid and liquid conductors. It does not hold, however, in all cases for the current through gases. It may be expressed in symbols:

$$\frac{E}{i} = R \qquad \text{or} \qquad i = \frac{E}{R}$$

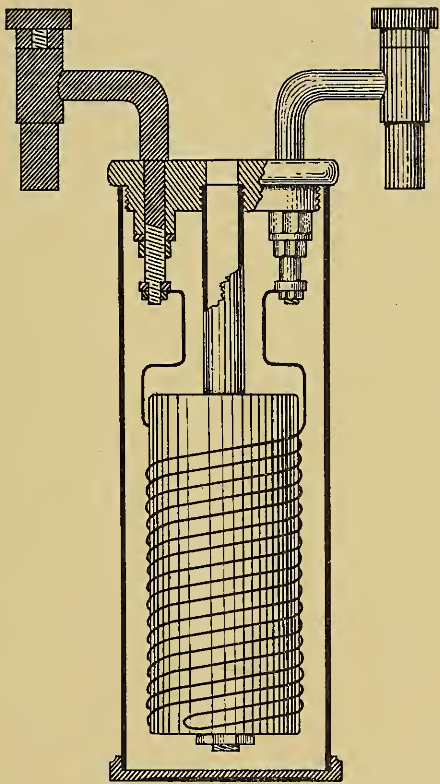
where E, i, and R stand for the E. M. F., current and resistance respectively. The reciprocal of the resistance, $1/R$, is called the *conductance* or *conductivity*, and is a measure of the readiness with which the conductor allows the passage of electricity.

[1] From André Marie Ampère, an eminent French scientist, who investigated the properties of the electric current. In strictness it should be stated that the fundamental unit is really the ampere, which is defined by the magnetic effect of the current (see note, p. 67), and that the coulomb is derived from this as the quantity of charge transferred each second by one ampere.

[2] The German physicist, Georg Simon Ohm.

Unit of Resistance.—A conductor is said to have unit resistance when a unit E. M. F. will produce a unit current. In this case i, E, and R in the formula above are each unity. In the practical system this unit is called the *ohm*, and is the resistance of a conductor in which the difference of potential of one volt between its ends produces a current of one ampere. As it is very desirable to have a concrete standard, careful experiments have determined that an ohm is represented by the

Fig. 18



Standard ohm.

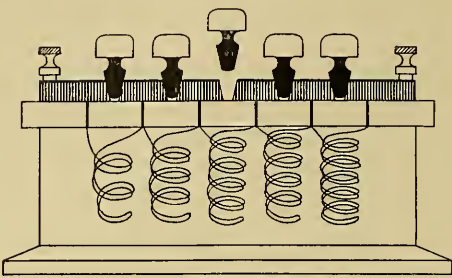
resistance of a cylindrical column of mercury 106.3 cm. long and of total mass 14.4521 grams (so that the cross-section shall be 1 sq. mm.) when at a temperature of 0° C.[1]

For convenience of use, coils of wire having the same resistance (or multiples of it) are used as working standards. Such a standard ohm is represented in section in Fig. 18. The heavy terminals are the electrodes where the E. M. F. is applied. Fig. 19 represents the construction of a set of standard resistances, known as a resistance box. The

[1] Legally in the United States the ohm is *defined* as above, the volt being defined in terms of the ohm and ampere.

ends of the coils are connected to heavy metal blocks. Metal plugs inserted between the blocks "short circuit" the coils so that the current passes directly from block to block instead of through the coils. On the removal of a plug, the current flows through the coil below the plug. In this way any desired resistance may be introduced into a circuit.

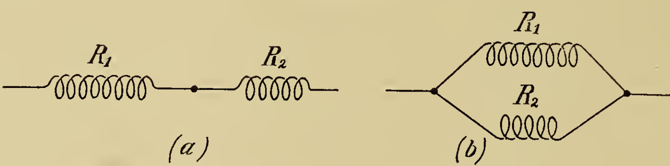
Fig. 19



Standard resistance box.

Laws of Resistance.—If several conductors are placed in series (Fig. 20, *a*), so that the whole current flows through all, the resistance is clearly the sum of the separate resistances. If the conductors are arranged in parallel (as in Fig. 20, *b*), the current is divided among the

Fig. 20



Two resistances: *a*, in series; *b*, in parallel.

different branches, and the resistance of the combination is decreased. In this case the *conductance* is equal to the sum of the conductances of the separate conductors, *i. e.*,

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \text{etc.}$$

The resistance of n wires in parallel is one nth of that of one. When there are only two conductors in parallel, the above formula reduces to

$$R = \frac{R_1 R_2}{R_1 + R_2}$$

i. e., the resistance of *two* conductors in parallel is equal to their product divided by their sum. Thus coils of 1 and 9 ohms in parallel have a resistance of

$$\frac{1 \times 9}{1 + 9} \text{ or } \frac{9}{10} \text{ ohm.}$$

It is evident from these considerations that the resistance of a uniform wire is directly proportional to its length and inversely to its cross-section, since a wire of double cross-section may be considered as two wires in parallel. The resistance of a wire of unit length and unit area of cross-section is known as the *specific resistance* of the substance. If this is known, the resistance of any other wire of the same material may be calculated by the formula:

$$R = \rho \frac{L}{A}$$

where ρ is the specific resistance, L the length, and A the area.

Variation with Temperature.—The resistance of almost all substances varies with the temperature. Most metals increase in resistance with rise of temperature, the increase for pure metals being greater than for alloys; while the resistance of other substances, such as carbon, salt solutions, etc., decreases as the temperature rises. Some substances, such as glass and the compound used in the glower of the Nernst lamp, are practically non-conducting when cold, but become moderately good conductors when heated to redness. A few alloys have been found to have practically no change of resistance with temperature. Of these, the best known is manganin, a compound of copper, nickel, and manganese. This is extensively used in the manufacture of standard resistance coils.

Rheostats.—Frequently a variable resistance is useful to regulate the current in a circuit. Such an arrangement is called a rheostat. It usually consists of a number of coils of wire which can be successively introduced into the circuit by turning a handle. A diagram will indicate the method of making connections (Fig. 21). The coils are shown at 1, 2, 3, etc. The handle which makes contact with the successive junctions between the coils is indicated at H. The rheostat is connected in series with the circuit at the points A and B. When the handle is placed as indicated, the first four coils are included in the circuit. As more coils are introduced, the current is correspondingly lessened.

Fig. 21

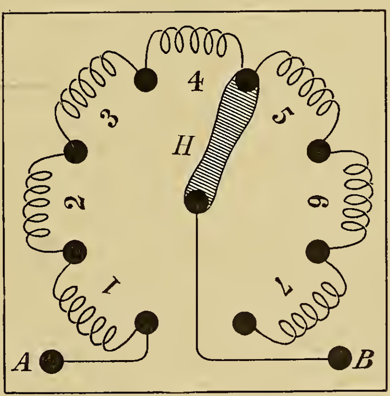


Diagram of rheostat.

A simpler device consists merely of a long coil of wire with a sliding contact, by which the length included in the circuit may be varied. Another type is composed of a vessel of some liquid conductor, such as salt water, in which are immersed metal plates connected to the terminals. The distance between

these plates, and hence the length of the conductor, is made adjustable, permitting a variation of the resistance.[1]

Shunts.—Another method of modifying the current in a conductor is to place it in one branch of a multiple circuit. The current is then divided, the larger part passing through the branch of less resistance. Thus, if the resistance of R_2 (Fig. 20, *b*, p. 44) is $\frac{1}{9}$ that of R_1, nine times as much current will pass through R_2 as through R_1, so that the current through R_1 will be only $\frac{1}{10}$ of the total current. The resistance R_2 is called a shunt, and R_1 is said to be shunted. By the use of a shunt of low resistance, large currents may be measured by a delicate instrument, as only a small fraction of the total current passes through the instrument (see p. 71).

HEATING EFFECT OF THE CURRENT

Conversion of Energy into Heat.—If two points of a conductor are at a difference of potential, a quantity of electricity in passing from the point of higher to that of lower potential must lose energy, just as water loses energy in flowing from a higher to a lower level. By the principle of the conservation of energy, this energy cannot be lost, but is converted by the passage of the current into some other form. Sometimes the energy of the current is used in producing chemical decomposition. Sometimes, as in the electric motor, it is converted into mechanical energy, and so on. Part at least of the energy of the current is used in overcoming the resistance of the conductor, and this is converted into heat, just as the friction of water flowing through pipes produces a similar transformation.

As heat is continuously produced as long as the current flows, the conductor rises in temperature unless the heat escapes as fast as it is generated. If too great a current passes, the conductor may be heated so much as to be injured. For this reason coils intended for heavy currents are made with a large radiating surface; and care must always be taken to limit the current passing through any piece of apparatus to the maximum for which it is designed. This is often done by including in the circuit a short piece of fusible wire which will melt and so interrupt the current before it is strong enough to cause any damage. Such a device is called a *fuse*. Fuses are now often made enclosed in cartridges, which prevent the metal when melted from falling on other apparatus. They are introduced into the circuit by simply slipping them into clips provided for them.

Joule's Law.—The law governing the heating effect may be readily deduced. For when a quantity of electricity, Q, falls through a differ-

[1] Still another very convenient and simple form of rheostat may be formed of a number of incandescent lamps suitably mounted on a board.

ence of potential, E, it loses an amount of electrical energy equal to $Q\,E$ (p. 28), or, since $Q = i\,t$ (p. 42), the energy transformed is

$$(1)\quad W = E\,i\,t$$

and where no other form of energy is produced this is all converted into heat. Now, from Ohm's law (p. 42), $E = i\,R$, which gives for the energy converted into heat

$$(2)\quad W = i^2\,R\,t.$$

The law expressed by these relations is known as Joule's law.

Measurement of the Heating Effect.—When the practical units are used, the energy is measured in joules (p. 23), and as it is known that the heat produced by the transformation of one joule is 0.24 calorie (a calorie being the heat which will raise by 1° C. the temperature of one gram of water), the quantity of heat developed by a current may easily be found. Thus, if a current of 5 amperes flows through a conductor of resistance 20 ohms for 30 seconds, the energy converted into heat is

$$i^2R\,t = 5^2 \times 20 \times 30 = 15{,}000 \text{ joules},$$

and the heat produced is

$$0.24 \times 15{,}000 = 3600 \text{ calories}.$$

Again, when 0.45 ampere flows through a lamp under a potential difference of 110 volts, the energy converted each second is

$$E\,i\,t = 110 \times 0.45 \times 1 = 49.5 \text{ joules}$$

and heat is developed at the rate of about 12 calories per second.

The *rate* of the conversion of energy is measured in watts (p. 23). Thus, to operate 10 such lamps as described above, energy must be supplied at the rate of 495 watts, or about half a kilowatt. The generator used must therefore be able to supply electrical energy at that rate. The expression for the power may be obtained by dividing each of the above expressions (1) and (2) by the time, thus obtaining

$$P = E\,i = i^2R.$$

From the first of these relations it is seen that

$$\text{Power} = \text{E. M. F.} \times \text{current},$$
$$\text{or,}\quad \text{Watts} = \text{volts} \times \text{amperes}.$$

Consequences of Joule's Law.—It follows from Joule's law that the heating effect *in a given conductor* is proportional to the *square* of the current strength. In different conductors the heating effect *of the same current* is proportional to the resistance. Thus, if pieces of iron and copper wire of the same diameter are joined in series and a current is

passed through them, the iron will be heated more than the copper, on account of its greater resistance, so that by increasing the current the iron may be heated to the melting point before the copper even begins to glow.

On the other hand, if *the same E. M. F.* is applied to different conductors, the heating effect will be proportional to the current (by (1) p. 47); and as the greatest current will flow in the conductor which has the least resistance, it follows that the heat developed will be greatest in that conductor. Thus, if two similar iron and copper wires are joined *in parallel* to the same E. M. F., the copper wire will receive the greater amount of energy and will become incandescent before the other. This result may be obtained from the expression (1), p. 47, by substituting the value E/R for i, thus obtaining

$$W = E^2t/R$$

which shows that for a given E. M. F. the heating effect is inversely proportional to the resistance.

Applications of the Heating Effect.—Applications of this effect are numerous. Perhaps the most important is the electric light. Here the resistance of a conductor is purposely made large so that it will be heated to incandescence, while the wires leading to it are of low resistance so that as little energy as possible will be wasted by heating them. In the common incandescent lamp the conductor consists of a thin filament of carbon, or, in some of the more recently constructed lamps, of tantalum or tungsten; substances being chosen which can be raised to a high temperature without melting. In the arc light (p. 53) the current passes across a gap between two carbon or metallic terminals, the heat being generated by the great resistance of the gap.

A similar application of the heating effect is the electric cautery. A small loop of platinum wire of high resistance is heated to a high temperature, while but little heat is generated in the copper leads. The essential principle utilized in all such contrivances is that the most heat is generated at those points of the circuit where the resistance is greatest, so that the expenditure of energy may thus be localized.

NATURE OF CONDUCTION

Classes of Conductors.—Conductors may be roughly divided into three classes according to the action of the electric current in passing through them. In the first class of conductors, to which the metals belong, the current produces no change in the conductor. This form of conduction is known as metallic conduction. The second class is composed of a number of chemical compounds and solutions. With these, the passage of the current is accompanied by a chemical change of the conductor. This is called *electrolysis* (decomposition by electricity) and a conductor

of this kind is called an *electrolyte*. The third class comprises the gases, which ordinarily are insulators, but which become conducting under the influence of great electrical stress, or of some other agencies.

Metallic Conduction.—In metallic conduction, no matter how great a current is passing, there appears to be no change of material at any point of the conductor, and the only effect produced in it is the rise of temperature. The charge seems to flow through the conductor like water through a pipe, or, to use a closer analogy, as heat flows along a bar which is kept hot at one end and cold at the other. There is no transfer of matter with the current. This can be seen by passing a current from one metal to another; there is no change of either metal. In the electron theory the current therefore is supposed to be composed entirely of the free negative electrons, which are the same in all substances and which pass through the spaces between the atoms when driven by an electric force. The positive charges, on the other hand, are inseparable or indistinguishable from the much larger atoms which in a solid are not free to move. In the analogy of the flow of water through a pipe we should therefore imagine the pipe full of pebbles, the water passing through the interstices. The resistance of the conductor to the current may be supposed to be due to the obstruction which the atoms offer to the free motion of the electrons, and the heating effect may be ascribed to the collisions of the electrons against the atoms.

Electrolytic Conduction.—The passage of an electrical current through an electrolyte is, as has been said, attended with chemical decomposition. This effect does not occur throughout the substance, but only near the places where the current enters and leaves the electrolyte. These places are called *electrodes*, the one of the higher potential being the *anode*, while that of the lower potential is the *kathode*. The components into which the substance is decomposed by the electric current are called the *ions*, those appearing at the negative pole being called *kations*, and those appearing at the anode being known as *anions*. The term *ion* is used not only for a constituent of the electrolyte as a whole, but also for one of the portions into which an individual molecule is split up.

A simple case of electrolysis is the decomposition of hydrochloric acid (HCl). Two platinum plates or electrodes are immersed in a vessel containing a solution of the acid, and are connected to the positive and negative poles of an electrical generator. As the current passes through the liquid no change is observed except at the electrodes. Bubbles of gas form upon these, the gas deposited on the anode or positive plate being chlorine, while hydrogen is liberated at the kathode. The compound HCl has been split up by the current into its components H and Cl. Again, in the electrolysis of a solution of copper chloride, chlorine appears at the anode, and the kathode becomes coated with a plating of copper.

It is important to distinguish between the character of the ions liberated at the two electrodes. Thus, the electropositive ion, hydrogen, or a metal such as potassium, sodium, mercury, zinc, copper, etc., is

liberated at the kathode, while the non-metallic elements: oxygen, sulphur, chlorine, iodine, etc., appear at the positive pole.

It does not always happen that the products of the decomposition actually appear at the electrodes, since often the result is complicated by secondary chemical reactions. Thus, when a solution of common salt (NaCl) is electrolyzed, the sodium which would be produced at the kathode combines with the water of the solution, forming sodium hydrate and setting free hydrogen. With sulphuric acid (H_2SO_4) the ion SO_4 formed at the anode liberates oxygen by combining with the water to form H_2SO_4 again; or if a suitable metal is used for the anode, the SO_4 combines directly with this, forming a sulphate. Similar secondary reactions in other cases will be understood from chemical considerations. In general, alkaline products are produced at the kathode, and acids at the anode.

Ionic Migration; Phoresis.—The transfer of the current is accompanied by an actual transfer of ions through the electrolyte. This is shown by studying the variation in the concentration near the electrodes. It is found that the positive and negative ions move in opposite directions and usually with different velocities, the positive, or kations, moving from the anode to the kathode and the negative, or anions, moving in the opposite direction. The migration will take place even through a porous barrier or a membrane, in which case it is known as *electric osmosis*, or *phoresis* (p. 114).

Laws of Electrolysis.—The relation between the current and the amount of chemical action is very simple: *The quantity of any ion liberated is proportional to the total quantity of electricity transferred.* This is known as Faraday's first law of electrolysis. Thus, in the passage of one coulomb through a solution of a silver salt, 0.001118 gram of silver is deposited on the kathode—the amount being exactly the same whether, for instance, one ampere flows for one second or 0.001 ampere for 1000 seconds. The quantity of an ion liberated by one coulomb is called the *electrochemical equivalent* of the ion. Thus, the electrochemical equivalent of silver as given above is 0.001118 gram; that of copper is 0.000329; of chlorine, 0.000367; of hydrogen, 0.0000104, and so on. These quantities have been carefully determined, and serve as a convenient means of measuring a current.

The second law of electrolysis refers to the relative amounts of different ions liberated by the same current. It may be stated as follows: *The electrochemical equivalents of different ions are proportional to their chemical equivalents or combining weights as compared with hydrogen.* Thus, in the compound hydrochloric acid, chlorine and hydrogen are combined in the proportions 35.5 to 1. But this is the ratio of the electrochemical equivalents. Again, when copper replaces hydrogen in the formation of copper sulphate from sulphuric acid, 31.5 times as much copper is dissolved as there is hydrogen generated; and the ratio of the electrochemical equivalents of copper and hydrogen is 31.5.

Theory of Electrolysis.—The explanation of these facts is bound up with the modern theory of solutions, according to which the molecules of electrolytes when in solution are split up into positively and negatively charged components, or ions. When two electrodes at different potentials are placed in the solution, the ions move in opposite directions according to the sign of their charge, and are deposited on their respective electrodes, giving up their charges. Unlike metallic conduction, the current is carried by both positive and negative charges, and the negative charges as well as the positive are associated with matter. By the first law of electrolysis all similar ions carry the same charge; and by the second law this charge is also the same for all ions which are chemically equivalent. Thus, the ions of H, Cl, NO_3, Ag, etc., all carry a charge of the same size; those of O, SO_4, etc. (which are equivalent to two H ions), carry twice this charge, and so on. Moreover, this smallest charge, that on the hydrogen ion, has been found to be the same as that on a single free electron. It appears, therefore, that a monovalent negative ion is a neutral atom (or group of atoms) with a single additional electron, a divalent ion is one with two added electrons, and so on, while the positive ions have a deficiency of one or more electrons (see also p. 21).

Conduction through Gases.—The phenomena attending the passage of electricity through gases are much more complex than in the other types of conduction. Under ordinary conditions a gas is almost a perfect insulator. If, however, the difference of potential between two points is increased sufficiently, the gas suddenly acquires a considerable degree of conductivity and a discharge takes place. This conductivity lasts only during the passage of the discharge, and as soon as the lowering of the potential causes this to cease, the gas returns to its insulating condition. On account of this intermittent breaking down of the dielectric, the phenomenon is known as the disruptive discharge.

The Electric Spark.—The character of the discharge varies greatly with the pressure of the gas. At atmospheric pressure it takes the form of a brilliant spark, which traces a more or less irregular path between the electrodes. The necessary potential difference is considerable, about 30,000 volts being required to produce a spark one centimeter long in air. This potential difference increases with the length of spark, though not in exact proportion, so that the spark length is often used as an approximate indication of the potential applied to the electrodes. The intensity of the spark depends upon the quantity of electricity passing, and is therefore much increased when the electrodes have a large capacity, for instance, when they are connected to the opposite sides of a condenser.

The Brush Discharge.—If the electrical field near a conductor is very strong, faint sparks will pass continually from the conductor to the air, producing what is known as the brush or glow discharge. As the quantity passing in each spark is small, this form of discharge is almost silent and is only faintly luminous. The effect is especially noticeable

around points and sharp edges, where, as was seen (p. 20), the density of electrification is greatest. This is known to electrotherapeutists as the effluve, the term brush discharge being applied by them to a different phenomenon (p. 245).

The Discharge in Rarefied Gases.—When the pressure of the gas is reduced, the discharge passes more readily and the spark becomes more diffuse, gradually spreading out into a wide luminous band between the electrodes. This effect is seen on a large scale in nature in the Aurora Borealis, which takes place in the upper and rarer layers of the atmosphere, as the lightning flash is a manifestation of the electric discharge in the denser regions. To produce the effect experimentally, the rarefied gas must be contained in a sealed tube. This form of discharge is often known as the Geissler discharge.[1] The most characteristic effects are observed when the pressure is of the order of a thousandth of an atmosphere. At still lower pressures the resistance increases again, so that a greater potential is necessary to produce the discharge, and this becomes less luminous, until, when the pressure has been reduced to approximately a millionth of an atmosphere, it is almost invisible.

The Kathode Rays.—At these high vacua the discharge appears to consist almost entirely of faintly luminous streams which issue perpendicularly from the negative electrode or kathode, and hence are called *kathode rays.* They travel in straight lines without reference to the position of the positive electrode, but may be deviated from their straight path by bringing a magnet near them. It has been shown by Sir J. J. Thomson that the kathode rays consist of negatively charged particles projected from the kathode with very high velocity. By experiments of marvellous ingenuity he was able to prove that these particles were a thousand times smaller than atoms—in fact, were disembodied particles of negative electricity, or, as we now call them, electrons.

The impact of the kathode rays produces a considerable amount of heat. This was demonstrated by Crookes, who concentrated the stream from a concave kathode upon a piece of platinum foil and heated it to incandescence. The impact also produces fluorescence in many substances. It was reserved for Röntgen, in 1895, to show that this impact also produces a peculiar kind of radiation which issues from the point struck by the kathode stream. To these rays the name of x-rays was given by the discoverer, but they are more appropriately designated as Röntgen rays. Their nature and properties will be discussed in a later section (p. 401).

Ionization of Gases.—While a gas is normally an insulator, it may be made conducting by exposing it to various agencies, among the most important of which are the Röntgen rays and the radiations from radioactive substances such as radium. The gas then acts as a conductor for small currents, so that an electrified body in contact with it will

[1] From the name of a celebrated glassblower of Bonn, one of the first to construct tubes in which these phenomena were exhibited.

lose its charge. It has been shown that the conducting property is due to the presence in the gas of charged particles or ions, which carry the current much as do the ions in an electrolyte. A gas in the conducting state is therefore said to be *ionized.*

The Electric Arc.—Another type of gaseous discharge is found in the electric arc. This differs from the spark discharge by being of much greater intensity of current, while the E. M. F. necessary to maintain it is considerably less. An arc is formed by bringing carbon or metallic electrodes into loose contact, so that the junction becomes heated to incandescence and partially vaporized on account of the large resistance. The terminals are then separated a short distance, and the current is carried by the hot vapor which thus forms the arc. The amount of energy expended is so great that the electrodes are maintained in an incandescent condition. The arc between carbon electrodes is extensively used for lighting. On account of its high temperature it contains a greater proportion of ultraviolet rays than other sources of light, a circumstance which has led to its use in the Finsen lamp as a therapeutic agent. For the same reason the mercury vapor arc, formed by using mercury as the negative electrode in an exhausted tube, is sometimes employed therapeutically. In order to obtain the full effect of the ultraviolet light, the tubes, lenses, etc., should be made of quartz, since ordinary glass is opaque to this kind of radiation.[1]

Theory of the Gaseous Discharge.—The phenomena of the passage of electricity through gases are so complex that it is impossible adequately to discuss their theory here. It may be said in general that all forms of the discharge are due to the presence of ions, so that the current, like that of electrolytic and metallic conduction, consists in the transfer of charged particles. In the kathode stream these particles are the free electrons themselves; in other cases they are combined with atoms or groups of atoms. For a complete treatment of the phenomena and theory of the gaseous discharge the reader is referred to Sir J. J. Thomson's *Conduction of Electricity through Gases.*

ELECTRICAL GENERATORS

Classes of Generators.—The principal devices for producing a difference of potential may be roughly divided into four classes. The first class comprises the "static" electrical machines, which utilize the principle of electrostatic induction, and in which the energy is derived from the mechanical work done in producing the electrical separation. The second class includes thermo-electric generators, in which there is a conversion of heat into electrical energy. In the third class are included generators such as voltaic cells, where the current is produced by chem-

[1] A special kind of glass (known as *uviol glass*) is sometimes used, which is somewhat transparent to ultraviolet light, though not so much so as quartz.

ical action. Such cells are common sources of the so-called galvanic, constant, or direct current. Finally, the various types of electromagnetic generator, whose action depends upon the relations between electricity and magnetism, form the fourth class. Of these, the first has already been described (p. 35), and a discussion of the last must be postponed until the subject of electromagnetism has been taken up (p. 81); accordingly this section is limited to the consideration of the second and third types of generator.

Thermo-electric Generators.—When two dissimilar substances are brought into contact, a difference of potential is produced. Therefore, if a circuit is composed of several conductors, there will be a potential difference at each junction. It was shown by Volta that if the conductors are all metals at the same temperature, these differences will balance each other and no current will flow around the circuit. Thus if a circuit is formed of two metals there will be a contact potential difference at each junction; but when the temperature is the same, these will be exactly equal and will neutralize each other. There will therefore in this case be no current. If, however, the junctions are at different temperatures, then, since the difference of potential depends upon the temperature, they will no longer balance and there will be a resultant E. M. F. producing a current. This device is called a thermo-electric couple. The energy of the current is drawn from the heat supplied to maintain the difference of temperature.

The E. M. F. produced by a single thermo-electric couple is very small, amounting to only a small fraction of a volt. The effect may be increased by having a number of junctions of two metals, the alternate ones being heated (Fig. 22). Such an arrangement is called a *thermopile.* The currents generated, however, are seldom sufficient to be of practical importance.

Fig. 22

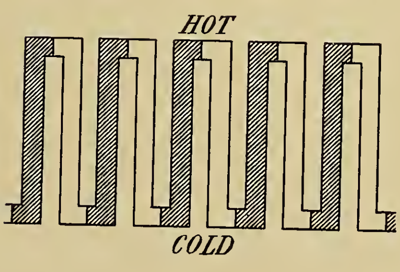
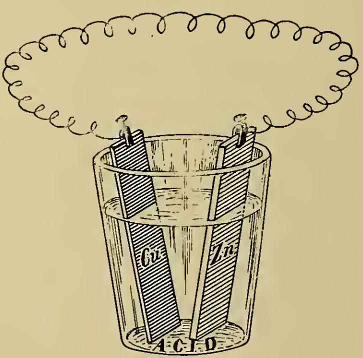


Diagram of thermopile.

Fig. 23



Voltaic cell.

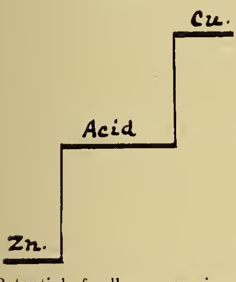
The Voltaic Cell.—As stated above, when a circuit of uniform temperature is entirely metallic, the various potential differences balance each other. If one of the metals is replaced by an electrolyte, the balance

is destroyed, and when the circuit is closed a current is produced. This is the principle of the voltaic or galvanic cell. The energy is derived from the chemical action which takes place between the electrolyte and the metals during the passage of the current.

A simple form of voltaic cell consists of two plates, one of copper and one of zinc, dipping in a solution of sulphuric acid (Fig. 23). The zinc plate is found to be at a potential about half a volt lower than the acid, while the copper is nearly an equal amount above, so that the copper is about one volt higher than the zinc. The conditions when the circuit is open are as represented in Fig. 24, where the height of the line represents the potential. Each conductor is throughout at the same potential.

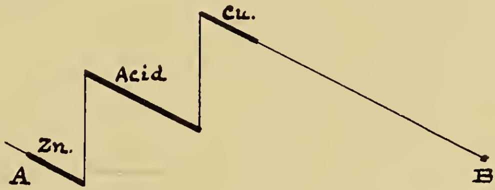
If the circuit is completed by connecting the plates by a wire outside of the liquid, as indicated in Fig. 23, a current will flow through the wire from the copper to the zinc, returning through the liquid from the zinc to the copper. The conditions will now be represented by Fig. 25. (The points A and B are supposed to correspond to the same point of the circuit.) There will be the same sudden rise of potential at each junction, but there will be a fall of potential in each conductor, represented by the downward slope of the lines. In the passage of the current through the acid, the ion SO_4 combines with the zinc, dissolving it, while hydrogen is set free at the copper plate (p. 49).[1] The energy of the current is here supplied by the chemical energy liberated in the solution of the zinc.

Fig. 24



Potential of cell on open circuit.

Fig. 25



Potential of cell on closed circuit.

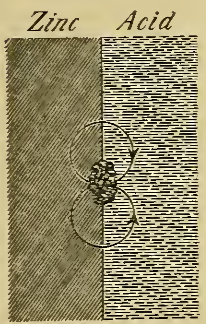
Electromotive Force of a Cell.—The algebraic sum of all the contact potential differences in a voltaic cell is known as the electromotive force of the cell. This is equal to the difference of potential between the terminals when the cell is on open circuit. When a current is flowing there is a fall of potential in the cell itself, so that the difference of potential between the terminals of the cell is, in general, less than the E. M. F. of the cell. Thus, it is easily seen from Figs. 24 and 25 that the difference of potential between the copper and zinc is less when the current is flowing than when the circuit is open by the amount of fall of potential through the acid.

[1] Since the current *in the acid* flows from the zinc to the copper, the zinc acts as the anode and the copper as the kathode.

The E. M. F. produced by a single voltaic cell is of quite a different order of magnitude from that generated by a static machine. It is usually between one and two volts, while that of the machine may be several hundred thousand. On the other hand, the current which may be obtained from a cell is many times as great as that from a machine, amounting in some cases to several amperes. On account of these great differences, the phenomena attending the passage of the current in the two cases have many points of contrast. The differences are only of degree, however, not in the kind of electricity produced, and, in fact, by the use of many thousand cells in series (see p. 61), or by other devices for raising the potential, which will be considered later (p. 85, etc.), the phenomena of so-called static electricity may be reproduced.

Polarization and Local Action.—The simple form of voltaic cell described above does not work in a satisfactory manner. The bubbles of hydrogen collect on the copper and diminish the current. This difficulty, which is called *polarization,* is overcome by using materials which will absorb or prevent the formation of the hydrogen. Another defect is known as local action. Pure zinc will not readily dissolve in acid without the aid of a current, but if there are impurities present these will form little circuits in the liquid (Fig. 26), dissolving the zinc without producing any useful effect. To avoid this, the zinc is amalgamated so as to present to the liquid a surface of uniform composition.

Fig. 26



Local action.

Primary Cells.—There are a great many types of voltaic cell in use, differing in the materials used and the methods of overcoming polarization. In almost all cases the metal of lower potential—the one more readily acted on by the liquid—is zinc, while copper, platinum, or carbon is commonly used for the other. A cell in which the energy is obtained from the decomposition of the materials of which it is constructed is called a primary cell. Either a single cell or a combination of cells is sometimes called an electric battery. While it is impossible to describe all forms of cell, a few of the more common types will be selected.

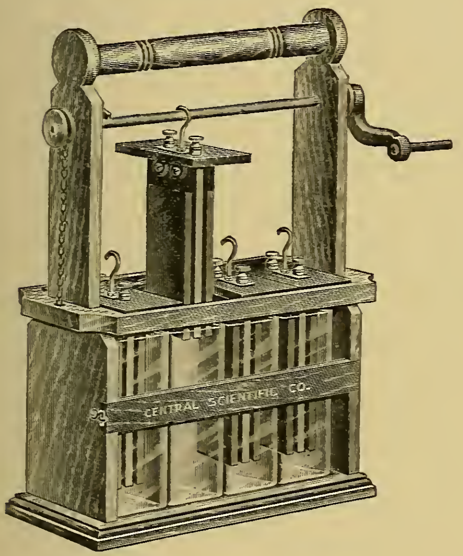
The Bichromate Cell.—In this cell, carbon and zinc plates are immersed in a solution of bichromate of potash and sulphuric acid. The liquid acts as an oxidizing agent and prevents the formation of hydrogen on the carbon plate. As the acid attacks the zinc even when the cell is not in use, it is not an economical form to use for intermittent work. The cell is often arranged so that the zinc may be lifted out of the liquid when the current is not flowing. When thus arranged it is sometimes called a plunge battery (Fig. 27).

Another means of protecting the zinc is to separate it from the carbon by placing the latter in a vessel of porous earthenware. The oxidizing

solution is contained in this vessel, while the zinc is immersed in dilute sulphuric acid (Fig. 28). The porous partition prevents the strong acid from reaching the zinc, but does not prevent the passage of the current.[1]

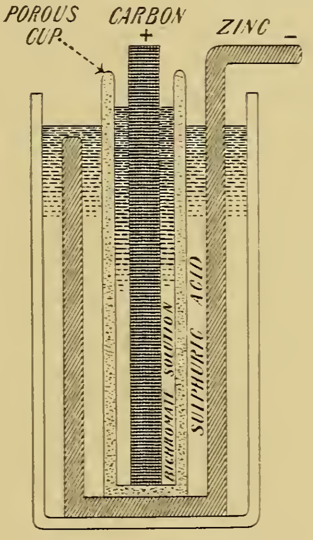
These cells have an E. M. F. of 1.8 to 2 volts. They produce a large current, but are expensive to maintain. As the cell is used the zinc is consumed and must be replaced. The acid also becomes reduced by the action of the hydrogen, and must occasionally be renewed. A change from the deep orange to a greenish color is evidence of the need of its renewal.

Fig. 27



Plunge battery.

Fig. 28



Cell with porous partition.

The Daniell Cell.—In the Daniell cell the copper plate is immersed in a solution of copper sulphate and the zinc plate in dilute sulphuric acid or a zinc sulphate solution, the liquids being separated by a porous partition as in the cell described above. Copper instead of hydrogen is liberated at the positive plate, and therefore there is no polarization. The porous partition is used to keep the copper sulphate from contact with the zinc plate, because the direct chemical action between them would result in coating the zinc with a layer of copper, thus destroying the efficiency of the cell.

In another form of the Daniell cell which is often used, the porous cup is dispensed with and the liquids are kept separated by their different specific gravity. In this form of cell, which is known as a *gravity*

[1] In this form of cell nitric acid is sometimes used as the depolarizer. The cell is then known as the Bunsen cell.

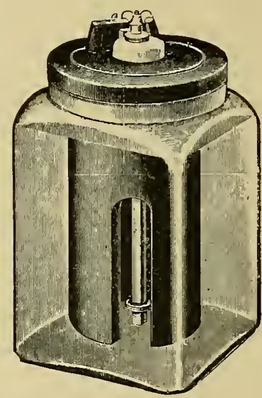
cell (Fig. 29), the solution of zinz sulphate floats on a denser solution of copper sulphate. The copper plate is placed in the bottom of the vessel, connections being made by means of an insulated wire, and the zinc is suspended in the upper part. Crystals of copper sulphate are put in the bottom to replace the salt that is decomposed when the current flows.

When these cells are not in use the liquids tend to mix by diffusion. They are therefore used only in what is called "closed circuit" work, *i. e.,* in cases where current is drawn continuously. All the care necessary is to prevent the exhaustion of the copper solution by adding fresh crystals occasionally; and to draw enough current to prevent the blue solution from diffusing up to the zinc. This form of cell gives a current which though not powerful is very steady. The E. M. F. is about 1.1 volt.

Fig. 29

Gravity cell.

Fig. 30



Sal ammoniac cell.

The Sal Ammoniac Cell.—In this cell the exciting liquid is a solution of sal ammoniac (NH_4Cl), the poles being carbon and zinc. As the liquid does not attack the zinc except when the current is flowing, this cell does not deteriorate on standing, and it is therefore of use in so-called "open circuit" work, such as ringing bells, etc., where current is drawn only occasionally. Sometimes the polarization is prevented by packing the carbon pole in granulated peroxide of manganese, which absorbs the hydrogen as it is formed. This form is known as the Leclanché cell. More often the depolarizer is omitted and polarization is diminished by making the carbon pole of large size and roughening it to facilitate the escape of the bubbles (Fig. 30). Such cells are very useful for intermittent currents, but polarize badly when used continuously. Their E. M. F. is 1.5 volts. After prolonged use the liquid becomes filled with zinc salts, which sometimes crystallize on the metal, stopping the current. The solution should then be renewed and the zincs cleaned.

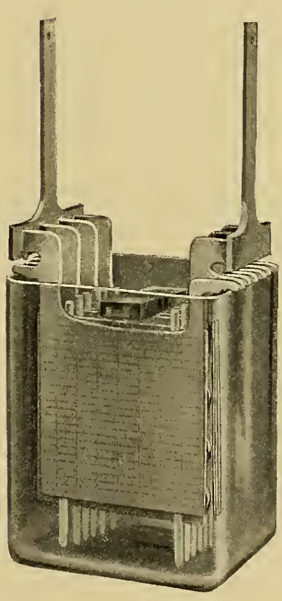
The Dry Cell.—Another form of the sal ammoniac cell is made by filling a zinc can with a paste of sal ammoniac mixed with some porous

material and with a suitable depolarizer. A carbon rod is inserted in the paste, and the can itself serves as the other pole. This form is very convenient, especially where portability is desirable, as there is no liquid to be spilt. It is not strictly dry, as the paste must be moist or it will not carry the current. The cell cannot be recharged, but must be thrown away when exhausted.

The Silver Chloride Cell.—This cell is very similar in principle to those last described, as the negative element is zinc and the exciting liquid is sal ammoniac. The positive pole is of silver coated with a depolarizing layer of silver chloride, which gives the cell its name. When the cell is in action, zinc chloride is formed by the solution of the zinc, while the NH_4 ion acts on the silver chloride, liberating silver. This form of cell is useful for small currents.

The Edison Lalande Cell.—In this cell copper oxide is used as a depolarizer, being compressed on the copper plate, which is immersed in a solution of caustic potash. The negative plate of zinc is immersed in the same liquid. The solution is protected by a layer of oil from the action of the carbon dioxide in the air. This cell has an E. M. F. of only 0.8 volts.

Fig. 31



Storage cell.

The Storage Cell.—The action of the primary cells described above depends upon the consumption of some of their constituents which must occasionally be replaced. In the secondary or storage cell[1] the renewal is accomplished by sending a current from another source through the cell in the reverse direction, thus reversing the chemical actions which occurred during its direct operation. There is here a conversion of electrical into chemical energy, the reverse of the transformation which takes place when the cell supplies the current.

The principal type of storage cell consists of plates of lead and lead peroxide (PbO_2) immersed in sulphuric acid, the lead being the negative pole. In order to increase the surface exposed to the liquid, a number of plates alternately positive and negative are often used, connected somewhat like the plates of a condenser (Fig. 31). When current is taken from the cell, the SO_4 liberated at the lead plate by the decomposition of the sulphuric acid forms lead sulphate ($PbSO_4$), while at the other plate the hydrogen together with free acid transforms the peroxide also into the sulphate.

[1] Also called *accumulator*

As this salt is insoluble, both plates finally become coated with it, and the cell ceases to give any current. It is then said to be discharged; but it may be charged again by sending through it in the opposite direction a current from an external source of an E. M. F. higher than that of the cell to be charged. The chemical action is now reversed. The SO_4 produces peroxide on the plate at which it appears, while the hydrogen reduces the other to metallic lead. The plates are restored to their former condition and the cell is again ready for use.

The storage cell forms a very convenient source of current where means are available for recharging it when exhausted. It requires little attention, though care must be taken not to send too great a current through it either in charging or discharging. The amount of electricity that may be obtained from a cell (its "capacity") depends upon the area of the plates. It is measured in coulombs or in ampere-hours,[1] and a cell of moderate size will deliver 50 to 100 ampere-hours before it must be recharged. The E. M. F. of the cell is about two volts.

While this form of cell is called a storage cell, it must not be thought that it accumulates an electric charge in the manner of a condenser. What is stored up in it when it is charged is energy, but this is in the form of chemical, not electrical energy, and the energy of the charged secondary cell is just as much chemical in its nature as that of a primary cell; though in the former case it has been produced by electrical agencies.

Application of Ohm's Law to Circuits.—In calculating the current flowing in a circuit it must be remembered that the generator itself opposes some resistance, so that there is a fall of potential in it as well as in the outside circuit. The total fall of potential must be equal to the E. M. F. of the cell (p. 55), *i. e.*, since Ohm's law applies to each part of the circuit,

$$E = Ri + ri$$

where R, r are the resistances of the outside circuit and of the cell respectively; whence the current is given by the expression

$$i = \frac{E}{R + r}$$

i. e., the current in a circuit is equal to the E. M. F. of the generator divided by the total resistance of the circuit. Thus, if a cell of 2 volts' E. M. F. and 3 ohms' resistance is connected to a conductor of 50 ohms' resistance, the current is

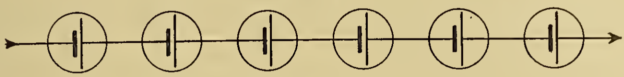
$$\frac{2}{50 + 3} = 0.038 \text{ ampere.}$$

Combinations of Cells.—When several generators are included in a circuit, the current produced depends upon the manner in which they are

[1] One ampere-hour = 3600 coulombs.

included in the circuit. They may be connected either in series or in parallel (p. 34), or in a combination of the two. When they are connected in series (Fig. 32[1]) the E. M. F. is the sum of the E. M. F. of the separate cells, while the resistance is equal to the sum of the

FIG. 32



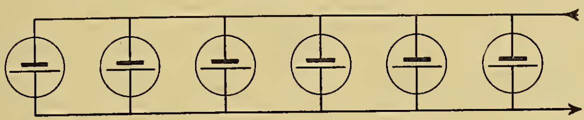
Cells in series.

resistances. Thus, if n similar cells, which each have a resistance r, are joined in series with an external resistance R, the total resistance of the circuit is $R + nr$; and if E is the E. M. F. of each cell, the total E. M. F. is $n E$. The current will therefore be

$$i = \frac{n E}{R + n r}.$$

This arrangement is the best whenever the external resistance is large, because in this case the increase of resistance of the battery is not of so much moment.

FIG. 33



Cells in parallel.

When similar cells are connected in *parallel* (Fig. 33), since all the similar poles are connected together, the E. M. F. is the same as that of a single cell. The advantage in this case lies in the decrease of the resistance that is obtained. Thus, when n similar cells are arranged in parallel the resistance of the battery is only $\frac{r}{n}$ (p. 44), so that the current becomes

$$i = \frac{E}{R + \frac{r}{n}}.$$

This method of combining cells is of advantage when the external resistance is small, because then more is gained by decreasing the resistance of the battery than by increasing the E. M. F. with its accompanying increase of resistance. It may therefore be taken as a general rule that cells should be arranged in series when the external resistance is high, and in parallel when it is low.

[1] In a diagram a cell is conventionally represented by the sign ▌|, the heavier line representing the negative plate.

A numerical example will perhaps assist in making this clear. If ten cells of E. M. F. 2 volts and resistance 3 ohms are connected in series to a conductor of 50 ohms' resistance, the current will be

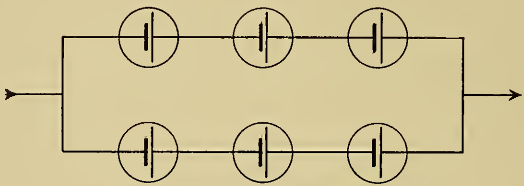
$$\frac{20}{50 + 30} = 0.25 \text{ ampere,}$$

while if these cells are joined in parallel to the same resistance the current will be

$$\frac{2}{50 + \frac{3}{10}} = 0.040 \text{ ampere,}$$

or little more than that given by one cell (p. 60). On the other hand, if the external resistance is $\frac{1}{10}$ ohm, a similar calculation will show that the cells in parallel will give 5 amperes, while in series only 0.66 ampere would be obtained.

Fig. 34



Cells in multiple series arrangement.

Sometimes, with an intermediate external resistance, a combination of these methods of connection is more efficient than either. Fig. 34 gives a diagram of such an arrangement. The working rule is, that to obtain the maximum current from a given number of cells, they must be arranged so that the resultant resistance of the battery shall be as nearly as possible equal to the external resistance.

CHAPTER III

ELECTROMAGNETISM

MAGNETISM

Magnets.—It has long been known that a piece of magnetite, one of the ores of iron, possesses in certain places, called poles, the property of attracting pieces of iron, and that such a natural magnet or lodestone, as it is called, will communicate this property to a bar of iron or steel which is rubbed upon one of its poles. An artificial magnet so formed usually has its poles situated at the ends of the bar. That the poles are not identical in properties is shown by the fact that when one will attract a given pole of another bar, the other will repel it; and the same law is found to hold as for electric charges, *i. e., like poles repel and unlike poles attract.*

When a magnetized bar is supported so as to be free to move, it takes a definite direction, one end pointing (nearly) to the geographical north. For this reason the poles are distinguished as the north-seeking and south-seeking poles, or sometimes as positive and negative poles. This property has had important application in the mariner's compass.

Magnetism a Molecular Phenomenon.—In one respect the magnetic properties differ from those of electrical charges—the two kinds of magnetism cannot be separated. If a bar magnet is broken in two, new poles immediately appear at the point of breakage, and this occurs however often the process is repeated; from which it appears that magnetism is a property not of the bar as a whole, but of the separate

Fig. 35

Molecular arrangement in an unmagnetized bar.

particles or molecules. We may picture a bar of iron as made up of a great number of molecular magnets. In the unmagnetized condition these point in all directions, so that they neutralize each other, as in Fig. 35; while when magnetized they are all directed more or less in the same direction, as in Fig. 36. In this case the diagram at once shows how in the interior the adjacent poles of opposite sign neutralize

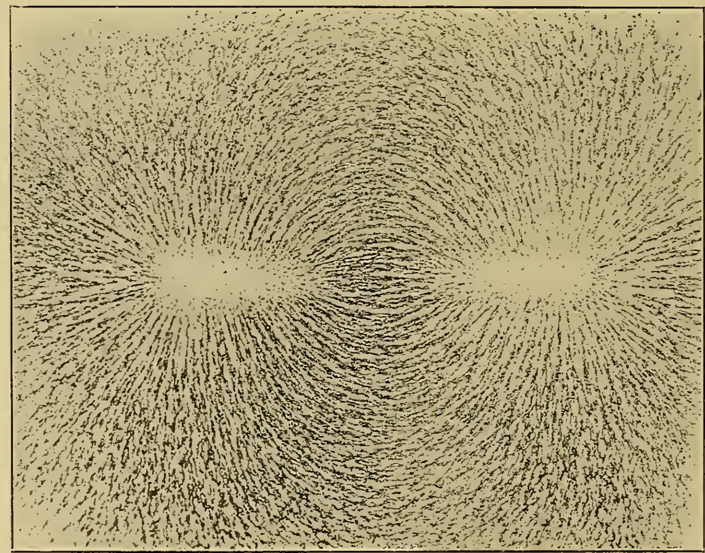
each other so that the unbalanced effect is exhibited only at the ends, and how new poles are formed wherever the magnet is divided.

Fig. 36

Molecular arrangement in a magnetized bar.

The Magnetic Field.—Just as there is an electric field in the space around a charged body, so there is a magnetic field in the neighborhood of a magnet. The lines of magnetic force are drawn in the direction of the force upon a north-seeking pole, and their distribution resembles that of the lines of electric force due to the analogous arrangement of charges.

Fig. 37



Magnetic field shown by filings.

As in the case of the electric field (p. 24), their number is made proportional to the strength of the field.[1] The field surrounding a magnet may be experimentally shown by scattering iron filings on a sheet of paper which is placed over the magnet. On tapping the paper, the filings arrange themselves along the lines of force, as in Fig. 37.

[1] The strength of a magnetic field is measured in the same way as that of an electric field, by the force upon a unit pole, the latter being defined as one that will repel an equal pole one centimeter distant with the force of a dyne.

When a freely suspended magnetic needle is brought into a magnetic field, it places itself along the lines of force, since its two poles are drawn in opposite directions along those lines. The needle therefore serves to indicate the presence and direction of the magnetic field, and it may therefore be inferred that there exists about the earth a magnetic field whose lines of force run toward the north. Experiment shows that they are not horizontal, but in the northern hemisphere are inclined downward, the angle with the horizontal being known as the dip or inclination. The earth, in fact, acts like a great magnet, as was first pointed out by Gilbert, who has been named above (p. 17) as one of the founders of electrical science.

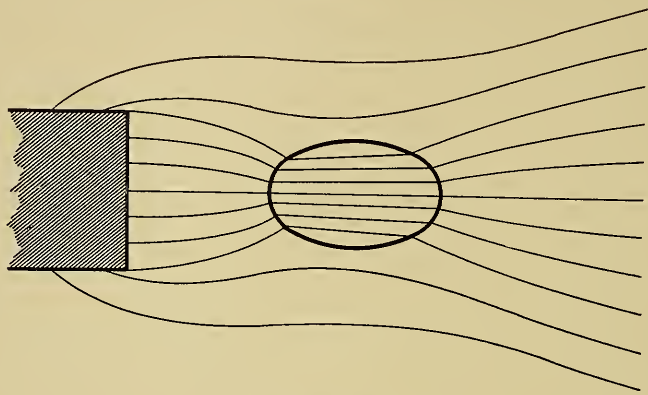
Magnetic Induction.—Another point of similarity with electrical phenomena is found in the phenomenon of magnetic induction. If a piece of iron is brought into a magnetic field, *e. g.*, near the pole of a magnet, it becomes itself magnetized in the direction of the lines of force, the pole nearer the inducing pole being of opposite sign to this. The intensity of magnetization increases with the strength of the inducing field up to a certain limit, beyond which the increase of the field has no effect. The iron is then said to be saturated. These phenomena may be explained by the hypothesis above stated (p. 63), that the particles of the iron are themselves magnets. Under the influence of the field they begin to turn in the direction of the lines of force, thus increasing the intensity of magnetization until all are turned in the same direction, when the iron is saturated. On removal from the field most of the particles fall back into their former irregular arrangement, but some remain in the new position, producing the permanent magnetism.

One peculiarity in this action should be noticed. While a piece of soft iron is readily magnetized by induction, it loses its magnetism almost entirely as soon as it is removed from the field. A piece of steel, on the other hand, while much less readily magnetized, retains permanently a large part of its magnetism. For this reason permanent magnets are made of steel; while soft iron is used whenever a strong though temporary effect is desired, for instance, in the cores of electromagnets and electromagnetic machinery generally.

Permeability.—On account of the magnetic induction the presence of iron greatly modifies the character of a magnetic field. Thus, if a piece of iron is placed in a uniform field, the lines of force are distorted so that a greater number will enter and leave the iron than if the field had remained unaltered (Fig. 38). While it is not possible to observe the lines in the material of the iron itself, they may be supposed to pass through the iron without break of continuity, as in the figure. To distinguish these lines from the lines of force without the iron they are called lines of induction. They may be regarded as the addition of the lines of force of the molecular magnets to those of the inducing field. The total number of lines passing through a given area whether of air or of iron is called the *magnetic flux* through the area.

The effect upon the field of the iron is to concentrate the lines in itself as if they pass more readily through iron than through air. For this reason, this property of iron is called *permeability*. It is measured by the ratio of the magnetic flux through a bar of iron placed in a field to the flux through the same space when the iron is removed. Its value differs with different specimens of iron, and is often as high as 1000 or more.

Fig. 38



Lines of induction.

The total effect of increasing the flux due to the permeability of iron in a field is not obtained unless the whole path of the lines of induction is through the iron. Even a small air gap materially reduces the amount. For this reason the most powerful magnets are constructed of horseshoe form in order to bring the poles closer, and the circuit is completed by a piece of soft iron called an armature or keeper.

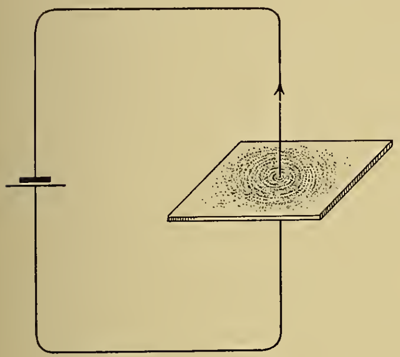
MAGNETIC ACTION OF CURRENTS

The Magnetic Field of a Current.—It was discovered by Oersted in 1820 that a current of electricity affects a magnet in its neighborhood; in other words, that a current produces a magnetic field. The effect is due to the *flow* of the electricity, as no static charges, however great, produce any such effect. The force exerted upon a magnetic pole is not one of attraction or repulsion, but is at right angles to the line joining it to the conductor, so that the lines of force have the form of circles concentric with the current. This may be shown by iron filings as in Fig. 39, or by noting that a small magnetic needle tends to place itself at right angles to the conductor carrying the current.

The direction of the lines of force, *i. e.*, the direction in which a north-seeking magnetic pole would move, is related to the direction of the current by the following rule: If a right-handed screw or corkscrew is

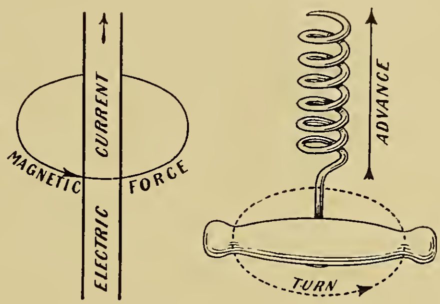
turned in the direction of the magnetic force, it *advances* in the direction of the current (Fig. 40). By this means it is easy to determine the direction of the current in a wire, by noting its effect upon a magnetic needle. Thus, when a current flows in a wire from south to north, the lines of force pass eastward over the wire, and westward under it. If, then, the north-seeking pole of a needle is deflected to the *west* by a current passing *over* the needle, the current flows from south to north. Other cases may be similarly interpreted.

Fig. 39



Magnetic field of current.

Fig. 40



Relation between current and magnetic field.

Field of a Circular Current.—If the wire is bent into a circle, an application of the rule just given will show that all the lines of force will pass through the loop from the same side. The relation of the directions is given by a similar rule: If a screw is *turned* in the direction of the current, it *advances* along the lines of force. The force at the centre is proportional to the current and to the number of turns, while it diminishes as the size of the loop is increased.[1]

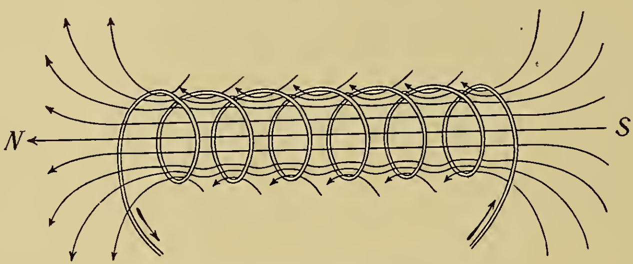
The Solenoid.—When the wire is wound in a long spiral of one or more layers it is called a *solenoid*. The resulting field is practically the same as if a number of circular loops were piled on one another. The lines of force pass axially through the coil, in the direction given by the rule stated above, and are curved where they enter and issue from the ends, so that they resemble the lines of force produced by a bar magnet (Fig. 41). In fact, a solenoid acts like a bar magnet, one end attracting a positive pole while the other repels it.[2]

[1] As the magnetic field at the centre of a coil is proportional to the current, the latter may be measured by the strength of this field. A unit of current has been defined in this way and is known as the c. g. s. electromagnetic unit of current. It is the current which produces, at a centre of a coil of unit radius, a magnetic field numerically equal to the length of the wire. The strength of the field is measured as stated in the note, page 64. It has been found convenient to select as the practical unit of current not this unit itself, but one-tenth of it. This is the definition of the *ampere*, which is the fundamental unit of the practical system. (See note, page 42.)

[2] In the construction of coils for standard resistances and other purposes this magnetic effect is sometimes undesirable. It is avoided by doubling the (insulated) wire on itself before winding it into a coil. The current thus passes around the coil first in one direction and then in the other, and no magnetic effect is produced.

The Electromagnet.—If a core of soft iron is placed inside a solenoid through which a current is flowing, it becomes magnetized by induction from the magnetic field of the solenoid. On account of the greater permeability of the iron, the magnetic flux through the solenoid is considerably increased. In this way a powerful magnet is obtained, which, however, loses its strength almost completely when the exciting current is interrupted. Such a device is called an *electromagnet,* and is much stronger than a permanent magnet of the same size. Electromagnets are extensively used not only where powerful magnetic fields are desired, as in the field magnets of dynamos, motors, etc., but also where a mechanism is to be controlled at a distance, as in the telegraph, electric bell, etc., the simple closing of a switch bringing the magnet into action.

Fig. 41



Lines of force of a solenoid.

Action of a Magnetic Field on a Current.—Corresponding to the force exerted by a current upon a magnet, there is a reciprocal action of a magnetic field upon a current. This may be observed if the current instead of the magnet is free to move. Thus, if a coil carrying a current is hung in a magnetic field so as to be free to move, it will turn so that its plane will be at right angles to the lines of force of the field. Again, a solenoid if free will place its axis in the direction of the field. The general law is that the coil moves so as to include as many lines of magnetic force as possible. In applying this law, the positive direction of the force is related to that of the current by the screw rule.

Since a stream of charged particles is equivalent to a current, this also will suffer a deviation when in a magnetic field. It is by this means that it has been shown that the kathode stream observed in the electric discharge through gases consists of negatively charged particles as described above (p. 52).

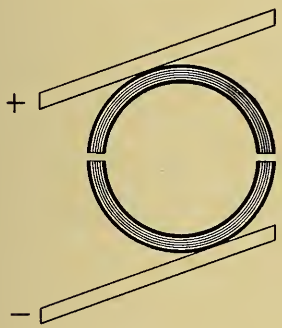
The Electric Motor.—This principle finds an important application in the electric motor. If a coil is mounted on an axis between the poles of a U-shaped magnet,[1] and a current is passed through it, there will be a

[1] The magnet is usually an electromagnet, excited from the same source that supplies the current to the coil. Either the whole current is sent through both in series (series winding) or it is divided, a small portion passing through the coils of the magnet (shunt winding). The connections are the same as those of the dynamo which are figured later (see p. 82 and Figs. 56 and 57).

force tending to rotate the coil until its plane is at right angles to the field. By an appropriate device the current is reversed just as the coil passes through this position, so that the force now tends to turn the coil into the reverse position. By this means a continuous rotation will be produced, which may be transferred to other apparatus by belts or gearing if desired.

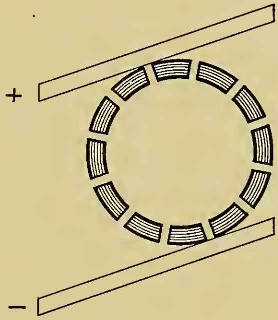
The device for reversing the current is called a *commutator* (Fig. 42). The ends of the coil are connected to two segments on the axle which are insulated from each other. Upon these segments rest metal or carbon pieces called *brushes*, which serve to lead the current to and from the coil. Every time that the coil makes half a revolution, the segments touched by the brushes are interchanged, and therefore the direction of the current is reversed. By appropriately placing the brushes this reversal may be made to occur at the proper time.

Fig. 42



Commutator.

Fig. 43



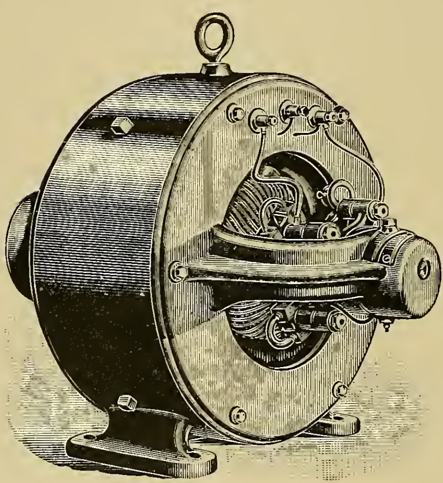
Commutator for six coils.

In order to increase the effect and to secure greater steadiness, a number of coils are usually mounted on the same axle in different planes, so that the force is more evenly distributed during the revolution. In this case the commutator is provided with a corresponding number of pairs of segments, as in Fig. 43, which is a section of the form of commutator when six coils are used. The axle with its coils and commutator is called the armature of the motor.

When a motor is running, the energy of the current is transformed into mechanical energy, very little being wasted in heat, as the resistance is made small. If, however, the full E. M. F. is applied directly to the motor when it is at rest, the energy, which is then all converted into heat, would be so great that the armature would become overheated and injured before the motor could start. For example, if a 3 kilowatt (4 horse-power) motor with a resistance of $\frac{1}{10}$ ohm is operated by an E. M. F. of 100 volts, the current through the motor is 30 amperes (since (p. 47) 3000 watts = 100 volts $\times$ 30 amperes), and the power lost by heat is $i^2R = 30^2 \times \frac{1}{10} = 90$ watts, or about 3 per cent. But

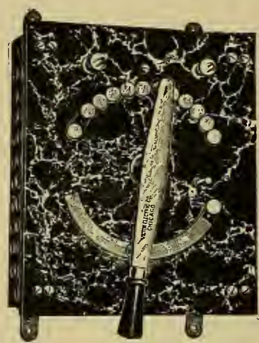
if the circuit is closed while the motor is at rest, a current of $100 \div \frac{1}{10} = 1000$ amperes will pass through the coils, with a heating effect of 100,000 watts. To avoid this danger of overheating, a large motor is provided with a rheostat placed in series with it, called a starting box. When the circuit is closed the resistance is all in series, but is gradually lessened (by turning the handle) as the motor gains speed, until it is finally cut out entirely.[1] Such a rheostat also furnishes a convenient means of controlling the speed of a motor. Fig. 44 illustrates a common type of motor, and Fig. 45 a starting box.

Fig. 44



Motor for direct current.

Fig. 45



Starting box.

The Galvanometer.—The mutual action of currents and magnets has been applied in the construction of instruments for the measurement of the electric current. Such an instrument is called a galvanometer. There are two leading types of galvanometer. In the first, a magnetic needle is pivoted or suspended in the centre of a coil through which the current passes. If the coil is placed with the plane of its loops vertical and in the magnetic meridian, the needle will be acted on by two fields; that of the current which tends to turn it east and west, and that of the earth which acts to restore it to the north and south position.[2] As a result the needle takes up an intermediate position, depending on the strength of the current. This position may be read on a divided scale or similar device, and if the values of the scale divisions are determined, the current may thus be measured.

[1] An automatic device frequently used protects the motor from being accidentally started with the resistance cut out. The handle of the starting box is provided with a spring which keeps it normally in the position where the resistance is all in circuit. When it is turned to the other extreme position it is held by an electromagnet, which acts only when the motor is running. As soon as this is stopped the handle is released and springs back to its former position.

[2] Sometimes the field of an auxiliary magnet is substituted for that of the earth.

In the second form, which is in more common use, and is known as the moving coil galvanometer, a coil of fine wire is suspended so as to be free to rotate between the poles of a magnet. In the normal position the coil is parallel to the lines of force between the poles, but when a current flows it is rotated toward the perpendicular direction until the opposing force (which is here due to the twist of the supporting wire or to a spiral spring attached to the coil) counterbalances the effect. By observing the angle the current may be determined as before. Instruments of this type are in extensive use, and are often graduated directly in amperes or fractions, in which case they are called *ammeters, milli-ammeters,* etc. Fig. 46 illustrates a commercial form of ammeter.

Fig. 46

Ammeter.

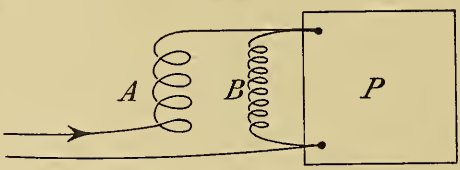
The Shunted Ammeter.—In measuring heavy currents which would injure the moving coil, recourse is had to the *shunt method.* A low resistance shunt (p. 46) is connected across the terminals of the ammeter so that all but a definite small fraction of the current passes through the shunt. (Thus, if the shunt is of $\frac{1}{99}$ the resistance of the ammeter, it carries 99 per cent. of the current, while only 1 per cent. passes through the ammeter.) As the current through the ammeter is proportional to the total current, the instrument may be graduated in terms of the latter. Most commercial instruments are thus provided with a shunt which is placed permanently in the case. Sometimes several shunts are provided, with separate terminals, so that the same instrument may be used for currents of different magnitude.

The Voltmeter.—A galvanometer may also be used to measure the E. M. F. between two points. For by Ohm's law, the current flowing through it is proportional to the difference of potential between its

terminals. When graduated to read directly in volts it is called a *voltmeter*. A voltmeter is not put in series with the current whose E. M. F. is to be measured, but as a shunt to this. Thus, if P (Fig. 47) is a motor or other device whose E. M. F. is to be measured, the voltmeter is connected across its terminals in the position of coil B, while an ammeter would be put in series with the current, as is coil A. In order that the conditions of the circuit shall not be altered by the introduction of the instrument, it is made of high resistance, or a high resistance is put in series with it, so that only a small current will flow through it. The commercial instruments are made exactly like the ammeter figured above except that a high resistance coil is permanently connected in series with the moving coil.[1]

Mutual Action of Currents.—As (p. 68) a force acts upon a current in a magnetic field, and as such a field may (p. 66) be produced by a current as well as by a magnet, it may be inferred that two currents act upon each other. This is, in fact, the case. Two parallel currents attract each other if flowing in the same direction, while they repel each other if flowing in opposite directions. When not parallel they tend to turn so as to become parallel. Two solenoids attract or repel each other just like two magnets. Advantage of this property is taken in the construction of measuring instruments without the use of magnets, as these may possibly vary in strength. Such an instrument is called an *electrodynamometer*, or current balance. A movable coil is suspended near a fixed coil and the force between them measured by a spring or by weights. The force is proportional to the product of the two currents, or, if the same current flows through both coils, it is proportional to the square of the current strength.

Fig. 47



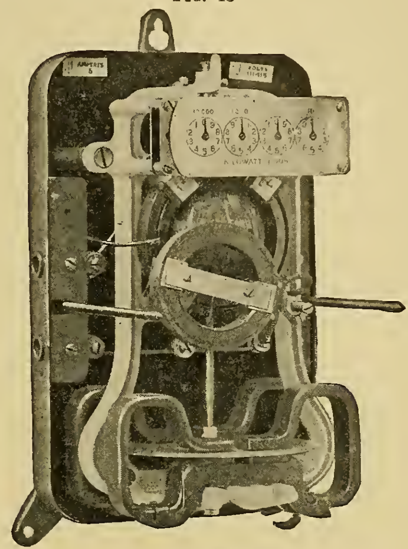
Connections of coils of wattmeter.

The Wattmeter.—An instrument of this type may also be used to measure the *power* consumed in any circuit, and is hence called a *wattmeter*. This is done by making one coil of high resistance and connecting it like a voltmeter so as to measure the E. M. F. of the circuit, while the whole current passes through the other coil. For instance, in Fig. 47 the whole current flows through coil A, while as coil B is of high resistance, it receives only a small current, which is proportional to the E. M. F. at the terminals of the power-consuming

[1] There are other types of voltmeter and ammeter depending upon other principles. Some of these will be described later (see p. 79).

device P. The force between the coils is proportional to the product Ei or to the power consumed in P (p. 47). Sometimes the force produces a continuous rotation of the movable coil, which is registered by a series of wheels and dials. The instrument then registers the *total energy consumed*, and might therefore be called a *joulemeter;* but is usually called an *integrating wattmeter* or a *watt-hour meter* (Fig. 48). In design this instrument is practically a small electric motor without iron. It is used extensively by companies supplying electric power, for the purpose of ascertaining the amount of energy furnished to consumers.

Fig. 48

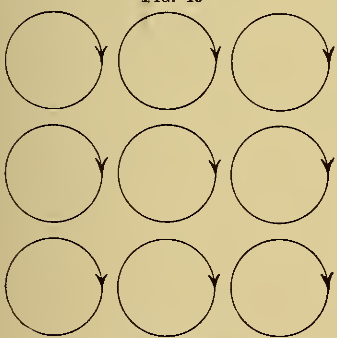


Integrating wattmeter.

The power consumed in a circuit may also be determined by measuring the current and E. M. F. with an ammeter and voltmeter respectively. The product of the readings will give the power in watts.

Ampère's Theory of Magnetism.—The similarity between the action of solenoids and magnets led Ampère to the hypothesis that magnetism is simply an electrical phenomenon and that the magnetism of the particles of iron is due to currents of electricity circulating about them. In more modern expression we may suppose one or more electrons to be circulating around each atom of iron, thus producing a small circular current which will have all of the properties observed. If several of these elementary currents facing the same way are placed side by side (Fig. 49), it will be noticed that the currents in the adjacent parts of the circuits flow in opposite directions and so neutralize each other, so that the effect is the same as that of a single current around the periphery. The molecular currents in a magnetized bar are thus equivalent to a current around its lateral surface.

Fig. 49



Amperian currents.

ELECTROMAGNETIC INDUCTION

Phenomena of Electromagnetic Induction.—The production of an electric charge by an electric field has been called electrostatic induction. Similarly the production of a magnetic charge by a magnetic field has been called magnetic induction. These two classes of phenomena must be carefully distinguished from the production of *electric* force by a *magnetic* field, which has received the name *electromagnetic induction.*

The fundamental fact of electromagnetic induction is that *any change* in the amount of magnetic flux through a circuit generates an E. M. F. in the circuit, which lasts only while the change is taking place, and which, if the circuit is closed, produces a current. The magnetic field may be due to either magnets or currents, and the change of the flux may be caused either by relative motion of the circuit and the field, or by variation of the strength of the currents or magnets producing the field. The E. M. F. and current thus generated are called the *induced* E. M. F. and current. The phenomenon was discovered by Faraday, who established the fundamental law of electromagnetic induction, that *the induced E. M. F. is proportional to the rate at which the magnetic flux through the circuit varies.* When the circuit is in the form of a coil, the flux passes through each turn of the wire; in this case, therefore, the induced E. M. F. is also proportional to the number of turns in the coil.

The *current* induced when the circuit is closed depends upon its resistance, and is related to the induced E. M. F. and the resistance by Ohm's law. This current is of course added to or subtracted from any current which may be already in the circuit. The direction of the induced current is such that the lines of magnetic force due to the current itself (p. 67) pass through the coil in the *same* direction as those of the field when the latter is *decreasing,* and in the *opposite* direction when it is *increasing—i. e.,* they tend to counteract the change in the field. Thus, if a circuit is viewed from such a direction that the magnetic lines of force passing through it are directed *toward* the observer, an increase of their number will induce a current flowing clockwise, while a decrease will produce a counter-clockwise current.

In a certain sense, the phenomenon of electromagnetic induction is the converse of the mechanical action of a field on a current described on page 68. For it was seen that when a current passes through a coil, it tends to move so as to vary the magnetic flux through it; and we now see that a variation of the magnetic flux tends to produce a current.

As an example of electromagnetic induction, if a coil and the pole of a magnet are brought toward each other, a current is generated in the coil while there is relative motion, but ceases as soon as the motion is stopped. The amount of this current depends upon the rate of the motion. When the coil and magnet are separated, a current is induced

in the direction opposite to the previous one. Another method of producing an induced current is by the rotation of a coil in a magnetic field, for instance, between the poles of an electromagnet. There is an induced E. M. F. in one direction while the flux through the coil is increasing, and in the other when it is decreasing. The amount of this induced E. M. F. is proportional to the area of the coil, the number of turns of wire in it, the rate of rotation, and the strength of the field. Since the direction of the effect is reversed at every half revolution, the E. M. F. and current are termed *alternating*. The properties of such an alternating current will be described later (p. 77).

Lenz's Law.—Whenever an induced current is generated by the motion of a conductor or magnet, there is a production of electrical energy from mechanical energy, which is the converse of the opposite transformation discussed on page 68. The principle of the conservation of energy shows that in all cases the forces due to the induced currents must oppose the motion which produces them; if it were otherwise, electrical energy could be generated without any work. This principle is known as *Lenz's law,* which states that *the direction of the currents induced by the relative motion of conductors and magnets is always such that the forces between them oppose the motion.* This rule covers all the special cases previously discussed.

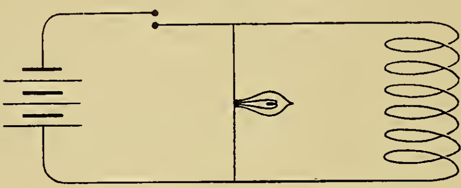
Mutual Induction.—Any other variation of a magnetic field will produce a similar effect. Thus, if two coils are placed near one another, the starting of a current in one will induce an instantaneous E. M. F. in the other, due to the magnetic flux thus suddenly caused to pass through it. As soon as the current in the first coil has attained its full value (which occurs in a small fraction of a second) the effect in the other coil ceases, showing that it was produced by the *change* of the current and not by the current itself. Interruption of the primary current produces an E. M. F. in the opposite direction. This phenomenon is known as *mutual induction,* and the coils are known as the primary and secondary coils respectively. If the coils are parallel it will be found, in accordance with the general law (p. 74) determining the direction of induced currents, that during the decrease of the current in the primary coil, the secondary E. M. F. will be in the same direction as this current, while during the increase of the primary current, an E. M. F. in the opposite direction is induced. An intermittent or alternating current will produce an alternating effect in the secondary coil.

Self-induction.—Just as the magnetic field of one circuit affects a second, so the field of a single circuit reacts upon the circuit itself. For when a current is started in a coil, the field thus generated induces an inverse E. M. F., which opposes the increase of the current and so prolongs the time necessary for the current to reach its maximum; and when a current is interrupted, the destruction of its magnetic field induces a direct E. M. F., which tends to continue the current. If the interruption is sudden, the E. M. F. may be very considerable and may

produce a spark at the point of breaking the circuit. This form of induction is known as *self-induction.* In general its effect is to oppose any change in the strength of the current.

If a second conductor is connected in parallel with the coil, as in the diagram (Fig. 50), so that after the battery circuit is broken there will be a closed circuit through the two conductors, the E. M. F. of self-induction will produce a momentary current around this circuit. Thus, if an incandescent lamp is connected in parallel with a low resistance electromagnet, the rush of current through the lamp when the circuit is broken may light it up even though the steady current was insufficient to do so. Or if the two ends of the coil are held in the hands, a sufficient current will be sent through the body to produce a considerable shock. This effect is practically applied in the medical coil (p. 89).

FIG. 50



Connections to show self-induction.

Inductance.—The magnitude of the E. M. F. of self-induction depends upon the rate of change of the current. It also depends upon the form of the circuit, as this determines the number of lines of force passing through it. Thus, when the circuit is in the form of a coil, the lines due to each turn pass through all the turns, and the effect is much greater than if the same wire is straight. The insertion of an iron core in the coil still further increases the effect.[1]

The property of a given circuit (depending on its shape, size, and the adjacent media), which, together with the variations of the current, determines the E. M. F. of self-induction, is called the *inductance*[2] of the circuit. It is defined as the total magnetic flux passing through the circuit when a unit current is flowing. In the practical system of electrical units, the unit of inductance is called the *henry.*[3]

Electrical Inertia.—The effect of self-induction on an electric current is closely analogous to the mechanical property of *mass* or *inertia.* The self-induction of a current opposes any change in the value of the current, just as the inertia of a body opposes any change in the velocity of the body. Thus, the time required to set a body in motion corresponds to the delay in starting a current after the E. M. F. is applied; and the

[1] On the other hand, if the coil is "doubly wound" (see note 2, p. 67) it is practically free from self-induction.

[2] Or, *coefficient of self-induction.*

[3] From Joseph Henry, the American investigator, who discovered the phenomenon of self-induction.

E. M. F. of self-induction produced on breaking a circuit is analogous to the force exerted by a moving body as it is brought to rest. The energy of a current is analogous to the kinetic energy of a moving body; with, however, the difference that the location of the energy is in the magnetic field surrounding the conductor and not in the conductor itself.

The nature of this energy is somewhat obscure, but it may be supposed to consist of whirls in the ether set in motion by the motion of electrical charges. Magnetic energy in this view is kinetic energy of the ether, while electrostatic energy is potential energy of ether-strain. The magnetic energy in turn tends to set electricity in motion, thus producing the effect of electromagnetic induction.

Summary of Electrical Units.—It may be useful here to extend the table given on p. 29 by adding to it the other electrical quantities which have been discussed above. The table given below includes all of the quantities in common use, with their relations as before. It may be added that the electrostatic units are very rarely used in connection with current phenomena.

Quantity.	Symbol.	Formula.	Prac. unit.	No. e. s. units in 1 prac. unit.
Work or energy	W		Joule	10^7
Power	P	$P = W/t$	Watt	10^7
Charge	Q		Coulomb	3×10^9
Potential or E. M. F.	E	$E = W/Q$	Volt	$\frac{1}{300}$
Capacity	C	$C = Q/E$	Farad	9×10^{11}
Current	i	$i = Q/t$	Ampere	3×10^9
Resistance	R	$R = E/i$	Ohm	$\frac{1}{9} \times 10^{-11}$
Inductance	L	$L = 2W/i^2$	Henry	$\frac{1}{9} \times 10^{-11}$

THE ALTERNATING CURRENT

Character of the Alternating Current.—The properties of an alternating current, such as, for instance, may be produced by a coil rotating in a magnetic field (p. 75), differ in some respects from those of a direct current. As there is no permanent transfer, but merely a surging of the current back and forth, there will be no decomposition of an electrolyte through which it may pass. Again, when an alternating current is passed through an ordinary galvanometer, the force between the coil and the magnet is reversed at each reversal of the current, so that unless the moving part (coil or magnet) is sufficiently light and mobile to follow these alternations, no effect will be produced.[1] On the other hand, the heating effect, which does not depend upon the direction of the flow, is the same as that produced by a direct current (p. 112).

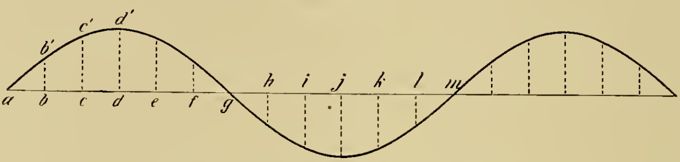
The simplest form of alternating current may be represented[2] by the

[1] An instrument of the moving coil type (p. 71), especially designed for the study of alternating currents, is called an *oscillograph*. The "coil" consists of a single loop of fine wire to which a very small mirror is attached. This is stretched in the field of a powerful magnet. The motion of the loop, which is rapid enough to follow the variations of the current, is usually recorded by photography.

[2] An alternating E. M. F. may be represented in the same manner as an alternating current.

curve of Fig. 51, where the vertical distances $b\,b'$, $c\,c'$, etc., represents successive values of the current at intervals of time represented by $b\,c$, $c\,d$, etc. During half of each revolution of the coil the current is reversed in direction, which is represented by plotting the curve below the horizontal line of reference. This curve is known as the sine curve, consequently a current of this character is called a *sinusoidal* current. Other more complex forms of alternating current or E. M. F. will be represented by different diagrams (see, *e. g.*, Fig. 53, p. 79), but they all consist in the repetition of a curve or wave composed of a positive and negative portion of equal area. The time of one complete alternation or cycle (as from a to m) is called the *period* of the current or E. M. F., and the number of alternations per second is called the *frequency*.

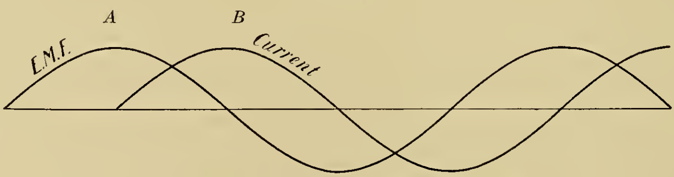
Fig. 51



Cycle of a sinusoidal current or E. M. F.

Effect of Inductance.—The relation between the current in a conductor and the external E. M. F. applied to it, which for uniform currents is expressed by Ohm's law, is greatly modified in the case of alternating currents by the self-induction of the circuit. For it has been seen that the E. M. F. of self-induction always acts so as to oppose any change in the current. The effect upon an alternating current is twofold. The

Fig. 52



Sinusoidal E. M. F. and current, showing lag.

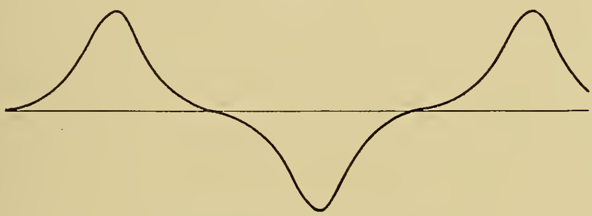
current is reduced below the value given by Ohm's law, and the alternations of the current lag behind those of the E. M. F., reaching their maximum somewhat later than the latter. Fig. 52, which represents the curves of an alternating E. M. F. and the current due to it, illustrates this second effect. The maximum of the current curve at B occurs at a later period than that of the E. M. F. at A, and the current is said to lag behind the E. M. F. in *phase*.

The amount of these effects increases with the inductance of the circuit and the frequency of the alternations. With even a moderate

amount of inductance it greatly exceeds the influence of the resistance. Thus, if an alternating E. M. F. of 10 volts making 60 cycles per second is applied to a small electromagnet of resistance $\frac{1}{10}$ ohm, the current will be only one or two amperes, while a direct E. M. F. of the same amount would give 100 amperes.[1] When the effect of the resistance is negligible, the current is one-quarter of a period behind the E. M. F., the case shown in Fig. 52.

Maximum and Effective Values.—In speaking of an alternating current or E. M. F., it is necessary to distinguish between its maximum value and what is called its effective value, *i. e.*, the value of the direct current or E. M. F. which would produce the same heating effect in a given conductor. The relation between the two depends upon the form of the wave; in the sinusoidal current the effective value is 0.7 of the maximum, while with a current such as is represented by Fig. 53 the ratio is much smaller. When the value of an alternating current or E. M. F. is stated without qualification, the effective value is always meant.

Fig. 53



Non-sinusoidal alternating current.

Measuring Instruments.—As the types of galvanometer or ammeter previously described are not affected by an alternating current, instruments depending upon other principles must be used. The most important of these may be classified under four heads:

1. *The Mutual Action of Currents.*—If the currents in two coils are simultaneously reversed, the force between the coils will always be in the same direction. An electrodynamometer (p. 72) will therefore measure an alternating as well as a direct current.

2. *The Attraction of Soft Iron by a Coil.*—A piece of soft iron is attracted by a solenoid in whichever direction the current flows. The force is therefore unchanged by the reversal of the current.

3. *The Heating Effect.*—In the "hot wire" instruments the current traverses a fine platinum wire, heating it and thus causing it to expand. The expansion is transferred to a dial, which may be graduated in terms of the current. The heating effect is the same (see above) whether the current is direct or alternating (Fig. 167).

[1] The value of an alternating current when the resistance is small may be calculated by the formula $i = \frac{E}{2\pi nL}$, where n is the frequency and L the inductance ($\pi = 3.1416$).

4. *Electrostatic Attraction.*—The attraction between a charge and the oppositely induced charge is independent of the sign. In the electrostatic voltmeter, suspended vanes are thus attracted by the fixed part of the instrument in which they swing.

All these instruments are calibrated by means of direct currents, and give the effective values of the alternating current or E. M. F. They may, of course, also be used for the measurement of direct currents.

Power is measured by the same form of wattmeter as used for direct currents (p. 72). It may be mentioned that when the current and E. M. F. curves do not coincide in phase, as in the example shown in Fig. 52, the power is *not* obtained from the product of the effective values of the current and E. M. F., but has a smaller value.

CHAPTER IV

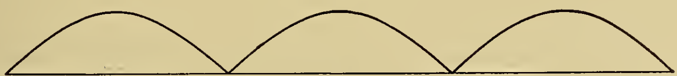
APPLICATIONS OF ELECTROMAGNETIC INDUCTION

THE DYNAMO

Principle of the Dynamo.—The most important practical application of the principles of electromagnetic induction is to the conversion of mechanical energy into electrical energy, and the production of a much more powerful source of an electric current than those previously described. The dynamo-electric machine, or, briefly, the dynamo, the apparatus by which this is accomplished, consists essentially of a coil mounted so as to rotate in a powerful magnetic field. In the details of its construction it is very similar to the electric motor (p. 68); indeed, the same machine may be used either as a motor or a dynamo. In the first case current supplied from an external source causes the rotation of the coil, while in the second the coil is driven by mechanical means and an electric current is produced.

When a coil is continuously rotated in a magnetic field it has been seen (p. 75) that the E. M. F. is *alternating.* The simplest form is that produced by rotating a coil with a constant velocity in a uniform field. Under these conditions the E. M. F. induced in the coil is *sinusoidal,*[1] and is represented by the curve shown in Fig. 51 (p. 78). The points *a, g, m,* where the curve cuts the horizontal line, correspond to the times when the coil is perpendicular to the field, for at these times the *rate of change* of the flux through the coil is zero, and the points *d* and *j* correspond to the positions of the coil parallel to the field, when the rate of change, and therefore the E. M. F. is greatest.

Fig. 54



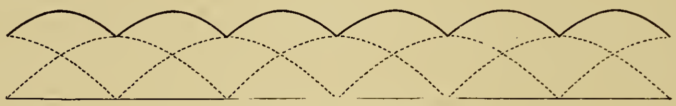
Pulsating E. M. F.

In order that the E. M. F. shall always be in the same direction, a commutator such as was described on page 69 (Fig. 42) is mounted on the axle of the coil, so that the contacts are reversed at the points *a, g, m,* etc. The E. M. F. of the external circuit will then be represented by a curve such as Fig. 54, and, while always in the same direction, will be pulsating, since it drops to zero twice in each revolution of the coil. This

[1]The current will also be sinusoidal, but will lag behind the E. M. F. on account of the inductance of the circuit (see p. 78).

defect is avoided by mounting a number of coils on the same axle, placing them at equal angles with one another, and increasing the number of commutator segments to correspond, so that it then takes the form shown in Fig. 43 (p. 69). By properly connecting the coils, the effects are added so that the maximum effect of one coil coincides with the zero position of another, and the result is more uniform. Thus, with two coils the E. M. F. will be as shown by the solid line in Fig. 55, and the variation is already greatly lessened. With a large number of coils, such as are used in large dynamos, the result is practically a uniform E. M. F.

Fig. 55



E. M. F. from two coils.

The Field Magnet.—In small machines the field is sometimes produced by permanent magnets. Such a machine is called a *magneto.* Usually, however, an electromagnet is used for the field magnet. In order to increase the strength of the field the pole pieces are made heavy and brought close to the armature, and the latter is wound on a core of soft iron. This is usually laminated or built of thin plates so as to avoid the induction of currents in the core itself, an effect which would cause a loss of energy.

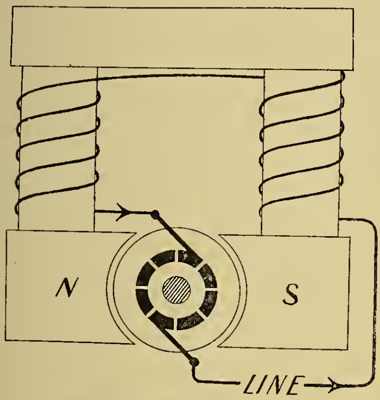
The field magnet is usually excited by the current generated by the dynamo itself. When a dynamo is first started there is a weak field between the poles, due to the permanent magnetism of the core. This field is sufficient to generate in the armature a small current which increases the strength of the field magnet as it flows through the coils. This in turn increases the armature current, and thus the field is gradually built up to its maximum strength.

There are two methods used to excite the field magnet, known as the series and shunt methods. In the series-wound dynamo the whole current passes through the field coils and the external circuit in series (Fig. 56). The field coils in this case are of heavy wire, so as to carry the large current. In the shunt-wound machine, which is represented in Fig. 57, the field coils are connected to the brushes in parallel with the external circuit, so that the current divides, part passing through the field coil and the rest around the external circuit. In this form of winding, the field coils are of comparatively fine wire of high resistance, so that only a small fraction of the current is diverted to them. Often a rheostat is put in series with them so that the strength of the field may be varied by altering the magnetizing current.

The choice between the methods of winding depends upon the purpose for which the current is used. In general, when a constant current is wanted the series form is used, while for a constant E. M. F. the more

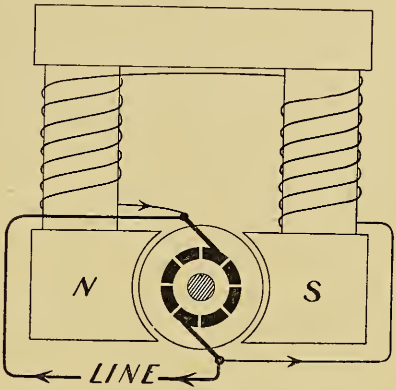
usual shunt-wound dynamo is employed. Sometimes a combination of the two windings is used on the same machine, which is then said to be compound-wound.

Fig. 56



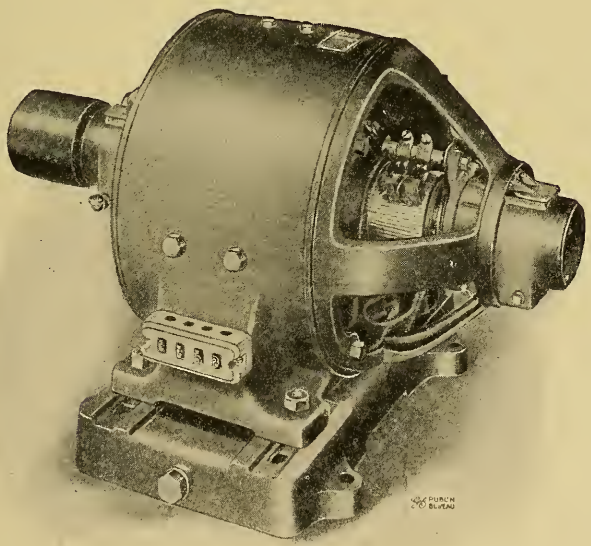
Connections of series-wound dynamo.

Fig. 57



Connections of shunt-wound dynamo.

Fig. 58



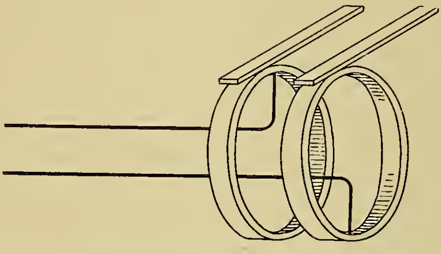
Multipolar dynamo.

Other Types.—The description given above is that of the simplest and most usual type of direct current dynamo, which is also that of the direct current motor. Often the design is modified for special purposes.

Thus, in the multipolar dynamo the field magnet has several pairs of poles arranged alternately around the armature. These modifications, however, will be readily understood by anyone who is familiar with the simpler type. Fig. 58 shows a common form of dynamo of the multipolar type. The commutator and one of the brushes may be seen in the opening of the casing which surrounds the machine and supports the field coils.

The Alternating Current Dynamo.—If in the single coil dynamo, described on page 81, the commutator is omitted and the ends of the wire of the armature are connected to two rings on which the brushes rest (Fig. 59), the E. M. F. and the current produced will be *alternating*, as described on page 77. Such an apparatus of the magneto type is often used for the production of a sinusoidal current, and known as a *sinusoidal apparatus*. If an electromagnet is used for the field magnet, it must be excited by a separate source of direct current, or by a small portion of the armature current rectified by a special commutator.

Fig. 59



Collecting rings and brushes of alternating current dynamo.

The design of alternating current dynamos or *alternators* is more varied than that of dynamos for direct currents. They are usually of the multipolar type, so that the frequency of alternation shall be greater for a given speed of rotation. In some forms the field magnets are made to revolve instead of the armature, and in others both are stationary and the field is varied by pieces of iron moving past the pole pieces. Sometimes several coils are mounted on the same armature in such positions that the separate maxima occur at different stages of the revolution. The currents are then, as it is said, in different *phases*. Such machines are called *polyphase* (two-phase, three-phase, etc.) alternators.

The Alternating Current Motor.—The alternating current dynamo may also be used as a motor, but its action is not as simple as that of a direct current motor. The machine must first be started and brought up to its proper speed by some external source before the current is turned on, otherwise the action of the field on the alternating current would be exerted first in one direction, then in the other, so that no rotation would be produced. On account of the necessary agreement in speed

with the generator, the motor of this type is called the *synchronous motor.* This inconvenience of starting limits its usefulness largely to cases where power is used continuously. Other types of alternating current motor simpler in their operation are known as the *induction motor* and the *repulsion motor.* In these the alternating current is sent through the field coils, while the armature is short circuited. The rotation is produced by the action between the alternating magnetic field and the currents induced by it in the armature.

One disadvantage of the alternating current motor is that the speed is largely determined by the frequency of the alternations, and therefore cannot be controlled so simply as that of motors operated with a direct current. Where it is necessary to obtain greatly differing speeds, some special mechanical device such as friction gearing may be used.

THE TRANSFORMER, ETC.

The Transformer.—The transformer is a device for changing the form of electrical energy from high to low potential, or *vice versa.* It consists essentially of two coils of wire completely insulated from each other, wound on the same iron core (Fig. 60). Then on account of the mutual

Fig. 60

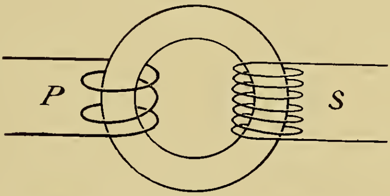


Diagram (theoretical) of a transformer.

induction between the coils (p. 75) any variation of the current in one will induce an E. M. F. in the other. The iron core is designed to form a closed magnetic circuit, so that all the lines of force produced by a current in either coil will penetrate the other, which gives a maximum effect (see p. 66). In practice an alternating current is sent through the primary coil, and therefore an alternating E. M. F. is induced in the secondary.[1]

One coil usually consists of a large number of turns of rather fine wire, while the other has a much smaller number of turns of coarser wire. In extreme cases only one turn is used. Either coil may be used as the primary or inducing coil. As the induced E. M. F. is proportional to the number of turns in the secondary coil, the fine wire coil is used as a secondary when the E. M. F. is to be raised, and the other when the opposite effect is desired.

[1] If only a direct current is available, it must be changed into an alternating current by some device, such as a *rotary converter* (p. 87).

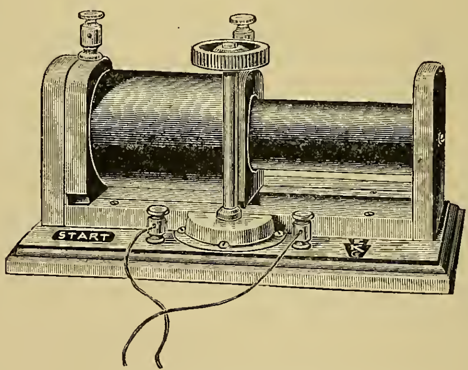
The ratio of the E. M. F. of the primary to that of the secondary current is approximately equal to the ratio of the number of turns in their respective coils. Thus, if the primary coil has ten times as many turns as the other, an alternating E. M. F. of 1000 volts applied to it will induce an E. M. F. of 100 volts in the secondary. Transformers operated in this way are in common use to "step down" a current of dangerously high E. M. F. to a safe value before admitting it into a building. If the coils are interchanged, the E. M. F. is increased in the same ratio, thus forming a "step up" transformer, which is a convenient device for obtaining an alternating current of higher potential than is given by the generator.

It must not be thought that energy is lost or gained in the transformation. Aside from a small loss due to heating the transformer, the energy obtained from the secondary current is equal to that supplied by the primary. An increase of E. M. F. is accompanied by a corresponding decrease of current, so that the product, which (p. 47) represents the power, is approximately the same. If the subscripts 1 and 2 refer to the primary and secondary coils respectively, we have approximately

$$E_1 i_1 = E_2 i_2.$$

Thus, in the step-down transformer described above, while the secondary E. M. F. is one-tenth that of the primary, the current will have ten times the value of the primary current.

Fig. 61



Small medical transformer.

In the small transformers used for medical purposes, one of the connections with the secondary coil is often arranged so that it may be joined to any part of the coil. By this device any desired number of turns of the secondary coil are utilized and the E. M. F. thus varied. Another method of regulation is to partially withdraw the iron core, or the primary coil, as in the transformer shown in Fig. 61.[1]

[1] See also methods of regulating induction coils, p. 92.

Rectifiers.—Electrical energy is frequently supplied in the form of an alternating current from an alternating dynamo or a step-down transformer. When a direct current is desired, for example, to operate a direct current motor or to charge storage cells, some device is necessary to convert the alternating current into a direct one. Such a device is called a *rectifier,* or *converter.*

One form of rectifier consists of a commutator (p. 69), driven by a synchronous motor which is operated by a portion of the alternating current itself. As the speed of the commutator corresponds to the alternations of the current, the reversals of connections on the commutator can be made to occur exactly when the current changes from a positive to a negative value. The action is in principle the same as that of the commutator of the direct current dynamo, where an induced alternating current is converted into a direct one.

A second method of conversion consists in driving a direct current dynamo by an alternating current motor of any type. The armature coils of the motor and dynamo may conveniently be mounted on the same axle over one another, so that the same field magnet is used. Closely analogous to this is the *motor generator,* or *rotary converter,* the armature of which has a single coil provided with a pair of rings (as in Fig. 59) at one end of the shaft, and a commutator at the other. When a source of alternating current is applied to the rings, and the machine is first speeded up to synchronism with it (by means of an auxiliary source of energy), it will continue to rotate and will supply direct current from the commutator.

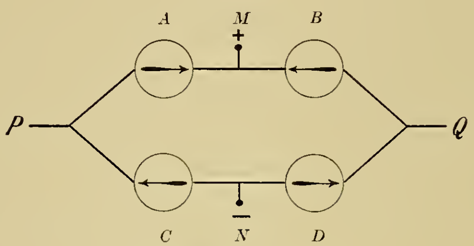
The type of rectifier described in the last paragraph may also be used to transform a direct into an alternating current, by supplying the direct current to the commutator brushes and taking off the alternating current at the collecting rings. This converse transformation is not possible with the rectifiers now to be described, which depend upon the assymmetrical properties of electrolytic conduction.

The *electrolytic rectifier* is often more convenient, especially for operations on a small scale. The action of this form of rectifier depends upon a peculiar property of aluminum when used as an electrode in an electrolytic cell. When an aluminum plate is made the anode, it offers a very high resistance to the passage of a current, while when used as a kathode no such action occurs. This action is produced by the formation upon the anode of a thin non-conducting film which almost completely prevents the passage of the current. When the aluminum forms the kathode, no such film is produced, or if one already exists it is at once broken down. If, therefore, an electrolytic cell with one electrode of aluminum and the other of some other metal or of carbon is placed in the circuit of an alternating current, it will permit the passage of the current only during the portions of the cycle when the aluminum electrode is the negative one.

In order to utilize both phases of the current, an arrangement of four cells connected as in the diagram (Fig. 62) is used. (One such

apparatus is known as a Nodon valve.) Here P and Q are the terminals of the alternating current, A, B, C, D are four cells, the arrows indicating the direction in which they permit the current to pass. The terminals from which the direct current is taken are at M and N. When the phase of the alternating current is such that P is positive, the current flows through A, from M to N, and through D, while B and C are inoperative. On the other hand, when Q is the positive pole the current flows through B, from M to N, and through C. In both positions of the cycle it is seen that the current flows in the same direction, from M to N, and that the terminal M (the one directly connected to the two aluminum electrodes of the cells) is the positive terminal of the rectified current.

Fig. 62



Connections for Nodon valve.

A number of different electrolytes have been suggested for use in these cells, among the most common being ammonium phosphate and caustic soda or potash. The nature of the second electrode is immaterial, so long as it is not attacked by the electrolyte. As the cell does not work efficiently when overheated, or when the voltage is too high, combinations of cells in parallel and in series respectively are used to obviate these difficulties. More complex arrangements are sometimes made to rectify polyphase (p. 84) currents.

The *mercury vapor rectifier* acts upon a somewhat analogous principle. A mercury vapor arc (p. 53) is formed between an iron anode and a mercury kathode. If the direction of the E. M. F. is reversed, the current ceases to flow. Such an arc, therefore, included in an alternating circuit, will serve to rectify the current. As the arc is not self-starting, some auxiliary device must be used to prevent its extinction during the reversal of the current.

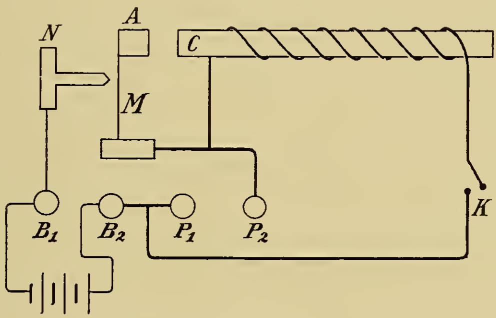
THE INDUCTION COIL

Principle of the Induction Coil.—One of the most important pieces of apparatus in which the phenomena of mutual induction are applied is the *induction coil*. This in principle is essentially a transformer, as it consists of two coils, a primary and a secondary, on the same iron core.

An alternating or intermittent current in the primary coil induces an alternating E. M. F. in the secondary. As the purpose of an induction coil is to produce a current of high E. M. F., the secondary coil is composed of a large number of turns of fine wire, while comparatively few turns of coarse wire are used in the primary.

The Singly Wound Medical Coil.—Before describing the induction coil itself, a simpler form of apparatus will be considered, the action of which depends upon the principle of self-induction. It consists of a single coil of about a dozen layers of wire wound on an iron core—in fact, an electromagnet—with a device for automatically making and breaking the circuit. The core, instead of being solid, is formed of a bundle of iron wires to prevent the formation in it of induced currents. A battery of one or two cells is sufficient for the operation of the coil. This form of apparatus is sometimes called an induction coil, though it is more customary to limit that term to coils having two separate circuits.

Fig. 63



Medical shock coil. Diagram of connections.

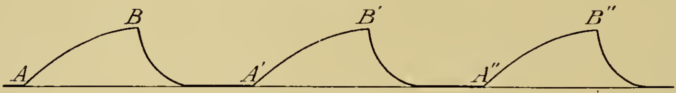
Fig. 63 gives a diagram of the connections. The interrupter consists of a piece of soft iron or armature, *A*, mounted on a spring, *M*, in front of one of the ends of the iron core, *C*. The spring, *M*, rests against a pin, *N*, the position of which is usually adjustable by a screw. This pin is connected through the binding post, B_1, to one terminal of the exciting battery, which consists of a few cells. One end of the coil is attached to the base of the spring, and the other terminates at the binding post, B_2, by which connection is made with the other battery terminal. A switch, *K*, is often introduced so that the circuit may be broken without disconnecting the wires.

When the battery is connected, it will be seen that the current flows through the primary coil by the way of the spring, *M*, and pin, *N*. As the core thus becomes magnetized, it attracts the iron armature, *A*, breaking the contact of the spring with the pin and opening the circuit. On the interruption of the current the core loses its magnetism and the armature springs back, restoring the contact. The process is then

repeated, producing a rapid vibration of the spring, each oscillation opening and closing the circuit.[1]

Each time that the circuit is closed, the current, by magnetizing the core, produces a powerful magnetic flux through the coil. This generates an inverse E. M. F. of self-induction in the coil (p. 75), which opposes the battery E. M. F. and delays the increase of the current to its maximum. When the circuit is broken the current falls much more rapidly, though not instantaneously, since the E. M. F. of self-induction, which is now direct, tends to continue it. The variation of the current in the coil may be represented by Fig. 64, where the points A, A', etc., correspond to the instants when the circuit is closed, and B, B', etc., to those of breaking the circuit.

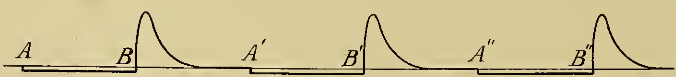
Fig. 64



Primary current in coil.

The direct E. M. F. induced on breaking the circuit is much larger than that of the battery. If proper electrodes are provided, this E. M. F. will send a current through the human body of sufficient intensity to produce a considerable shock. These electrodes are attached to the ends of the coil by the binding posts P_1 and P_2. The current delivered to them when the coil is in operation will consist of pulses which will always be in the same direction. It may be approximately represented by Fig. 65. The nearly horizontal portions between A and

Fig. 65



Primary induced current.

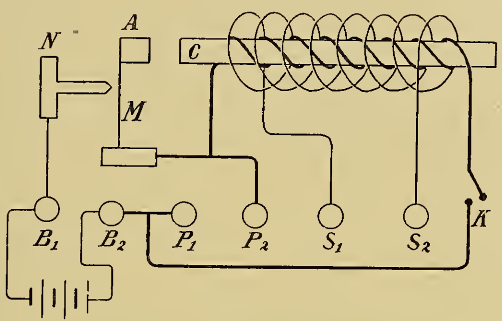
B, etc., represent the current due to the battery on closed circuit, and the points B, B', etc., correspond to the instants when the circuit is opened. This current is called the *primary induced current* or the extra current of self-induction. It must not be confused with the primary current in the coil shown in Fig. 64.

The Medical Induction Coil.—The small induction coil used principally for medical purposes (sometimes called a *faradic* coil), which is illustrated in Fig. 68, is almost exactly similar in construction to the apparatus just described, except that an additional or secondary coil, containing a considerable amount of finer wire, is wound over the primary, which is

[1] An essentially similar device is used to produce the vibrations of the hammer of an electric bell. Sometimes the interrupter is operated by an additional electromagnet in the same circuit.

now made of fewer layers. (In a coil of moderate size there will be two to four layers on the primary coil and fifteen to twenty on the secondary.) A diagram of the connections of such a coil is shown in Fig. 66. This may be seen to be exactly like Fig. 63, with the addition of the secondary coil and the binding posts S_1, S_2, by which connection is made with its terminals. The action of the battery current and interrupter is exactly as before, and the primary induced current is of the same character, though not so powerful because of the lessened number of turns in that coil.

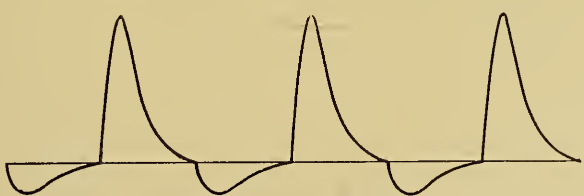
Fig. 66



Medical induction coil. Diagram of connections.

The Secondary Current.—The varying magnetic flux due to the interrupted current in the primary coil induces an alternating E. M. F. in the secondary. Its direction is that of the primary current while the flux is decreasing, and the opposite while it is increasing (p. 75). This secondary E. M. F. is much higher than the primary, because the same variation in magnetic flux takes place through a much larger

Fig. 67



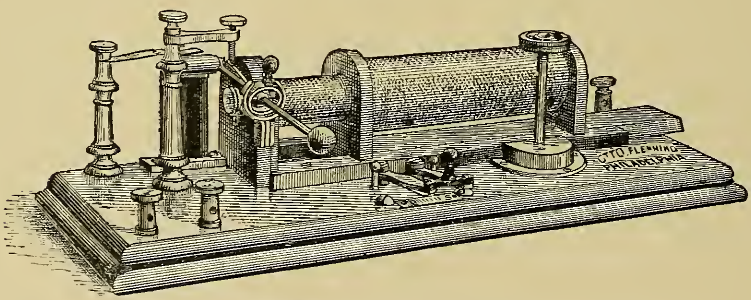
Secondary induced E. M. F.

number of turns. Moreover, since the self-induction of the primary coil causes the current in that coil to rise comparatively slowly, while the break is much more sudden, as seen in Fig. 64, the positive E. M. F. in the secondary coil is much greater than the negative. Fig. 67 exhibits the character of the secondary E. M. F., the negative portion of the curve corresponding to the closing of the primary current and the positive part to the break.

When the terminals of the secondary coil are joined through a conductor of high resistance, such as the human body, a current is produced of the same general character as the E. M. F. This current is, however, lessened by the self-induction of the secondary coil itself, which acts so as always to oppose the variations of the current. Thus, while the E. M. F. between the terminals of the secondary may be three or four hundred volts on open circuit, the effective value between the same points when a discharge is passing may be reduced to fifteen or twenty volts. Another effect of the self-induction is to smooth down the irregularities of the current.

It may be seen that the primary and secondary induced currents differ in two respects—the E. M. F. of the secondary is higher than that of the primary, and the secondary current is alternating while the primary is pulsating, but always in the same direction. In most coils terminals are provided, as at P_1, P_2, S_1, S_2, Fig. 66, by which connection may be made with either coil. Sometimes the coils are connected in series, a single terminal at the junction taking the place of the two connected primary and secondary terminals (P_2 and S_2, Fig. 66). By a proper choice of connections, either the primary or secondary or the two currents superposed may be obtained.

Fig. 68



Sledge form of induction coil.

Regulation of Current.—There are various methods by which the strength of either the primary or secondary current may be regulated. A variable resistance or rheostat (p. 45) may be put either in series with the battery or in the circuit whose strength is to be adjusted. Sometimes the secondary coil is wound in sections, so that by turning a switch a greater or less portion may be thrown into the circuit. In a form known as the sledge coil (Fig. 68), the secondary is mounted on a slide so that it may be wholly or partly withdrawn from the inductive influence of the primary coil. In other coils the iron core may be withdrawn, thus weakening the magnetic flux.[1] The principles of these methods of regulation are readily understood.

[1] In this case the interruptions of the primary circuit must be produced by a separate electromagnet.

Another means sometimes used for controlling the current perhaps needs fuller explanation. A brass tube is arranged so as to slip either over the core or over one or both coils. It is called a shield or damping tube, and it has the effect of diminishing both the primary and secondary current. The explanation of its action is that it practically forms a closed secondary circuit of one turn. Though the induced E. M. F. is small, the resistance is so low that a considerable current is produced, and this is of such direction as to oppose the inductive effect of the battery current, and to diminish the magnetic flux through the coils. As the tube is withdrawn, its effect is lessened and the currents increase in strength.

Spark Coils.—For producing more powerful effects, larger coils are constructed, acting on the same principle as those described above. The relative number of turns in the secondary coil is considerably increased, and much greater care is given to the insulation. A condenser added to the primary circuit greatly increases the efficiency, and the apparatus for interrupting the primary current is modified and adapted to the larger currents used.

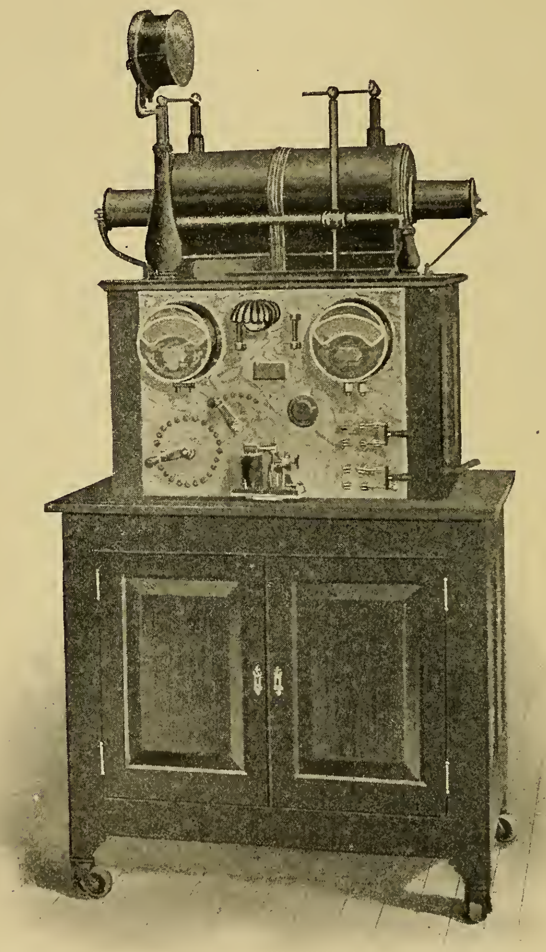
Such a coil (sometimes called a spark coil or a Ruhmkorff coil) will produce a discharge of very high potential, a large coil giving a spark several feet in length. The current also is greatly increased. These powerful coils are used with high frequency apparatus, and to produce the discharges in high vacua which are the source of the Röntgen radiation (p. 52). A coil of this character is shown in Fig. 69 (p. 94). The secondary coil, which contains many miles of wire, is carefully insulated from the primary. On the switchboard below the coil may be seen instruments for measuring the current, switches for controlling it, etc.

For these large coils the voltaic batteries employed with smaller coils are entirely inadequate. Recourse must be had either to a storage battery or to a dynamo. Many coils are designed to be excited from the usual lighting circuit of about 110 volts, a suitable rheostat being interposed. Where the lighting system is alternating it may sometimes be employed, as in high frequency work, but is unsuitable for other uses of the coil, such as the production of Röntgen rays. In this case a proper rectifier, preferably a rotary converter (p. 87), must be used. When a coil is operated on an alternating current circuit the interrupter is omitted, or its contact permanently closed. The action in this case is precisely like that of a transformer.

The Condenser.—It has been seen (p. 91) that on breaking the primary circuit a considerable E. M. F. is produced, due to the self-induction of the primary coil. This may be great enough to produce a spark or arc at the point of interruption, which prolongs the current and thus diminishes its rate of decay. The secondary E. M. F., which depends upon the rate of fall of the primary current, will therefore be increased by any device that will lessen the sparking at the break. This is accomplished by connecting the plates of a condenser to the opposite sides of the break, *i. e.*, to the points *M* and *N*, Fig. 66. It

will be remembered (p. 32) that the effect of a condenser is to diminish the potential of a charge, so that its addition here counteracts the induced E. M. F. of self-induction and reduces the potential difference at the gap. The tendency to spark at the break is thus greatly diminished. The "extra current" charges the condenser instead of leaping

Fig. 69



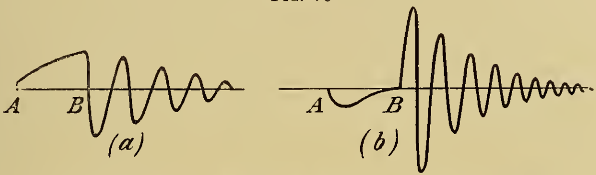
Large spark coil with switchboard.

the gap, and the circuit is broken much more abruptly. By this means the secondary E. M. F. is increased many times.

The presence of the condenser modifies the action of the coil in another manner. After it is charged as described, it discharges through

the primary circuit. As the discharge of a condenser under these conditions is usually *oscillatory*,[1] it will induce a secondary E. M. F. of the same character, *i. e.*, alternating with decreasing amplitude as the oscillations of the condenser die away. In this way an inverse E. M. F. will be produced at the break, which may be greater than that formed on closing the circuit. The curves in Fig. 70 represent the primary current and secondary E. M. F. of such a discharge. The points *A* and *B* mark the instants of making and breaking the circuit.

Fig. 70



a, primary current; *b*, secondary E. M. F. of coil with condenser.

The value of the capacity which gives the best result depends upon the self-induction of the primary coil modified by the effect of the secondary discharge. It is also dependent upon the strength of the primary current and the frequency of interruption. The condenser should therefore be adjustable, so as to meet the varying conditions of the operation of the coil, for too great a capacity is sometimes as disadvantageous as too little. It should be added that when the electrolytic interrupter (presently to be described) is substituted for one of the mechanical type, the condenser is unnecessary and should be omitted. As the necessary capacity is considerable, the condenser is usually made of sheets of tinfoil insulated by paper or mica and divided into sections, as described on page 33.

The Mechanical Interrupter.—The action of the interrupter exerts considerable influence upon the character of the induced currents. As its frequency is increased, the number of current impulses is correspondingly increased, without at first greatly changing the character of each discharge. But if the interruption becomes so rapid that there is not sufficient time for the battery current to reach its maximum before the circuit is broken, the amount of magnetic flux through the coil is lessened, with a consequent diminution of the induced E. M. F. The gain caused by the increase of frequency is thus counteracted by the weakening of each discharge. In order to obtain any desired frequency the speed of the interrupter should be adjustable.

With the simple form of interrupter described above (p. 89) but little can be done to modify the frequency. A slight change may be made by altering the distance through which it oscillates. Adjustable forms of interrupter are used on larger coils, where the frequency is altered by varying the tension on the spring or the load fastened to it.

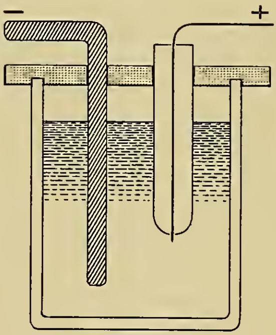
[1] The character of the condenser discharge is discussed on p. 98.

In all such mechanical interrupters an increase of tension causes a more rapid oscillation, while a greater load, or an increase of its distance from the fixed end of the spring, diminishes its rate. In a more complex design an adjustment is provided by which the duration of the contact at each oscillation may be regulated.

Of still more importance than the frequency of the interrupter is the manner in which the circuit is broken. Even with a condenser there is considerable sparking with the forms of interrupter described above. This not only diminishes the E. M. F. produced, but the heat of the spark may even fuse the contact points together.

This defect is partly overcome by the use of the mercury contact breaker. The contact is made and broken by metallic points attached to the vibrator, which dip into cups of mercury. A little oil or alcohol poured upon the surface of the mercury assists in producing a more abrupt break. In other forms of mercury break the contact piece is driven by an independent motor.

Fig. 71



Wehnelt interrupter.

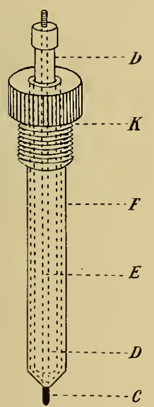
The Electrolytic Interrupter.—An interrupter working on a different principle is very efficient when a high frequency is desired. This is the *electrolytic* interrupter, of which there are two types. The Wehnelt interrupter (Fig. 71) is essentially an electrolytic cell with a very small anode. This anode consists of the end of a small platinum wire projecting from an insulating sheath of glass or porcelain, which with a lead plate forming the kathode is immersed in dilute sulphuric acid. The great current density at the anode produces considerable local heating at that point, and bubbles of gas form upon the platinum point on this account as well as on account of the electrolysis that takes place. As these bubbles completely cover the electrode, the circuit is broken, to be closed again as the bubbles escape. This produces a rapid interruption of the current, of a frequency, depending upon the strength of the current and upon the amount of the wire exposed.

Fig. 72 illustrates a form of anode frequently used. The platinum rod C is sealed in the lower end of a porcelain tube D D, through which

it is metallically connected to the positive end of the primary circuit. Over this tube slides a large porcelain tube, F, at the bottom of which is an opening just large enough to allow the platinum electrode to project. The screw K, which threads into a plate on the top of the electrolytic vessel, serves to adjust the amount of platinum exposed to the liquid.

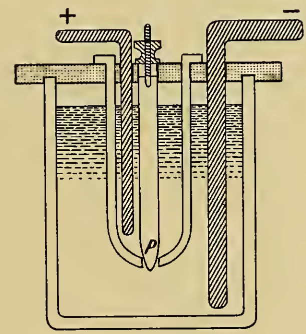
In another form of the electrolytic interrupter, due to Caldwell and Simon, both electrodes are large lead plates, but they are separated by an impervious partition pierced by a small hole. The formation of bubbles of steam now takes place at the hole, which is the point of greatest resistance, and the current is made intermittent as in the other form. Here the effect is entirely due to the heating effect of the current. The frequency of interruption depends mainly upon the strength of the current and the size of the hole. Fig. 73 shows a diagram of an interrupter of this type, in which the size of the hole can be regulated by screwing down the porcelain plug P.

Fig. 72



Anode of a Wehnelt interrupter.

Fig 73



Simon interrupter.

Character of the Induction Coil Discharge.—It has been shown that the E. M. F. induced on breaking the circuit attains much higher values than that in the opposite direction induced when the circuit is closed (see Fig. 65). When the secondary circuit is completed through a solid or liquid conductor, the discharge will therefore be alternating but unsymmetrical. But if the discharge takes place through a gas, the inverse E. M. F. may not be sufficient to produce a spark, so that the discharge passes in one direction only. The induction coil may therefore be used to produce a unidirectional current of high potential through a gas, such as is needed for the operation of x-ray tubes, etc.

If the gas resistance is too low, or if the oscillations of the condenser are of great enough amplitude, an inverse discharge will be produced. Where it is important that the discharge should be wholly in one direction, a device known as a valve tube may be introduced into the

7

circuit. One form of valve tube is an exhausted tube with electrodes differing greatly in size. It is found that an electric discharge will pass through this much more readily if the larger electrode is made the kathode. Such a tube therefore aids in the suppression of the inverse discharge (see p. 440).

When the interrupter is omitted and an alternating primary current is used to excite the coil, the secondary discharge becomes symmetrical. The negative half of the wave, however, may be suppressed by a valve tube if desired and the discharge thus made unidirectional.

ELECTRICAL OSCILLATIONS

The Oscillatory Discharge.—It has been mentioned (p. 95) that the discharge of a condenser is often oscillating, thus producing for a brief period an alternating current of very high frequency. The character of the oscillation may be understood by comparing it with the analogous case of a mechanical vibration. If a spring is pulled aside and then released, it will execute a number of oscillations of gradually decreasing amplitude until it finally comes to rest. The period of an oscillation increases with the mass of the spring and with its flexibility; so that the lighter or stiffer it is, the more rapidly it oscillates. As the resistance to the motion increases, the oscillations die down more rapidly, until finally, when the resistance is very great, as is the case when a light spring is immersed in a viscous liquid, the motion ceases to be oscillating, and the spring, when released, returns directly to its position of equilibrium.

In the same manner, when the terminals of a charged condenser are connected by a circuit of low resistance, the discharge which takes place is of an oscillatory character. The opposite plates of the condenser become alternately positive and negative as the charge surges back and forth, the loss of energy due to the resistance of the circuit causing a gradual decrease of the amplitude. The greater the resistance of the circuit, the more rapid is this decrease, until with a sufficiently high resistance the discharge takes place without reversal. The duration of an oscillation of the discharge depends mainly upon two factors—the capacity of the condenser, which has been seen (p. 29) to correspond to the flexibility of the spring, and the self-induction of the discharging circuit, which is analogous to inertia (p. 76) and which therefore corresponds to the mass of the spring. If either the capacity or self-induction is increased, the period of oscillation of the discharge increases.

The frequency of these oscillations is often very great. Thus, the period of discharge of a Leyden jar through a short discharging circuit will be less than a millionth of a second. With a smaller capacity, as when a discharge is produced between two small spheres, oscillations have been observed as brief as twenty billionths (20×10^{-12}) of a

second. On the other hand, the oscillations of the condenser through the primary of an induction coil, alluded to on page 95, on account of the large inductance and capacity, are of the order of a hundredth of a second.[1]

The "Skin Effect."—One peculiarity in the action of these high frequency currents is known as the "skin effect." A steady current distributes itself uniformly throughout the cross-section of a conductor. Thus, if a conducting wire is imagined to be made up of a number of equal fibers, each fiber will carry the same amount of current. But if the current is alternating, the variation of the current in each fiber will induce currents in the others which will partly neutralize the currents already existing in them. This effect will be greatest in the interior of the wire, where a given fiber is surrounded on all sides by others. The result is that an alternating current is not uniformly distributed through a conductor, but is stronger at the surface.

The effect is measurable even with alternating currents of the low frequencies given by a dynamo. It becomes much more marked with these rapid oscillations. The current is then limited to a thin outside layer of the conductor. The resistance of a conductor for these currents is therefore much increased and is proportional to the perimeter instead of the area of its cross-section. For this reason the same amount of material is a better conductor for an alternating current when in the form of a tube or thin ribbon than as a circular wire (p. 217).

Electric Waves.—The oscillating discharge of a condenser produces a series of electromagnetic waves in the ether, which travel outward with the speed of light. These are in some respects analogous to the sound waves which are produced by a vibrating body. The existence of these waves was predicted by Maxwell from his development of Faraday's theory; they were first observed in 1888 by Hertz, whose brilliant investigations of their properties form a striking confirmation of that theory. Their most important practical application is to the solution of the problem of wireless telegraphy.

The High Frequency (d'Arsonval) Oscillator.—These oscillations of high frequency are known as the d'Arsonval discharge. An arrangement of apparatus by means of which they may be obtained is shown in Fig. 74. I is an induction coil used to charge the condenser C. This may be a Leyden jar or an oil condenser (p. 33). S is a solenoid consisting of a few turns of heavy wire. When the condenser has been charged, it discharges through the solenoid S and across the spark gap G, producing oscillations of very high frequency around this circuit. Electrodes attached at points such as A and B will experience rapid alternations of potential.

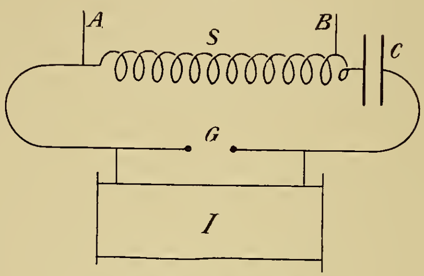
[1] The period of an oscillation, when the resistance is small, may be approximately calculated from the formula

$$T = 2\pi\sqrt{LC}$$

where L is the inductance of the circuit in henrys and C its capacity in farads.

The frequency of these oscillations must not be confounded with that of the induction coil discharge. This latter is determined by the rate of the interrupter, and amounts to perhaps a few hundred per second. Each of the discharges of the coil excites the condenser circuit and produces the much more rapid oscillations above described, the frequency of which is determined by the capacity and inductance of the circuit, and may amount to millions per second. On account of the

Fig. 74



Connections of d'Arsonval oscillator.

high resistance of the spark gap these oscillations rapidly die away, so that they have disappeared before the next discharge of the coil excites them anew. The variation of potential is somewhat of the character shown in Fig. 75, except that the intervals between the successive discharges are proportionately much longer.

Other Forms of Oscillator.—A modification commonly made in the oscillator above described is the use of two condensers, C_1 and C_2, in series with the solenoid S instead of one. The connections are as shown in Fig. 76. It may be seen that the solenoid is thus insulated from the direct discharge of the coil. An additional advantage is that the large difference of potential is now shared between two condensers.

Fig. 75

Form of oscillator discharge.

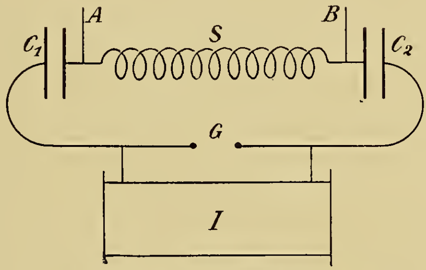
Where the induction coil is replaced by a static machine or by the secondary of a step up transformer, similar effects will be produced. With the transformer the condenser is charged alternately in opposite directions at the reversals of the primary current, but this does not modify the character of the discharge. The transformer current, however, is usually of lower potential but greater intensity than that from the coil or machine, and this will cause a corresponding change in the current of the oscillating circuit.

The *indirect methods of discharge*[1] of the static machine described on pages 231 and 258 bear a close analogy to the arrangement of oscillator above described. Thus, on examination of Figs. 187 and 226 it will be seen that a circuit is formed by the condensers and spark gap similar to that in Fig. 76. While the solenoid is omitted, the inductance of the circuit may be sufficient to produce oscillations in the discharge.

Electrical Resonance.—One of the most striking phenomena connected with electrical oscillations is that of *resonance.* If a circuit receives a series of electrical impulses of the frequency corresponding to its natural rate of vibration, oscillations of considerable amplitude are set up in it, while impulses of different frequency produce little effect. These impulses may be produced either by connecting the circuit with a second oscillating circuit or by the inductive action of such a circuit.

The behavior of an electric circuit is exactly analogous to the corresponding action, likewise known as resonance, of a mechanically vibrating body, such as a spring, a tuning fork, or an air column. For example, if

Fig. 76



D'Arsonval oscillator with two condensers.

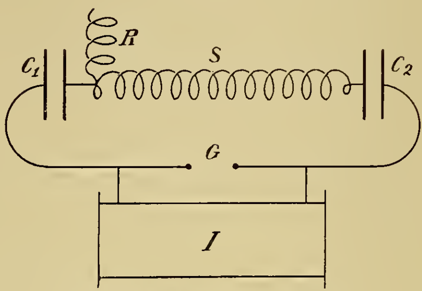
a tuning fork is held over a column of air which is of such a length that its free vibrations are of the same frequency as that of the fork, the air column will be set into vigorous vibration and will strongly reinforce the sound of the fork; but even a slight alteration of its length destroys this resonance by throwing the air column out of tune. The explanation of the effect is that when the impulses are timed so as to affect the body when in the same condition or phase of vibration, they all conspire to assist the motion, so that the amplitude increases until the increase of the frictional losses absorbs the whole of the energy supplied. On the other hand, if the impulses are not in synchronism with the natural vibrations, they no longer assist each other, and the motion produced is much less.

The Resonator.—A form of resonator often used with high frequency apparatus consists of a large spiral of one layer of wire wound on an insulating support. The wire need not be coated with insulation, but the adjacent turns are separated by a few millimeters so as to avoid a

[1] Known as static induced and static wave currents.

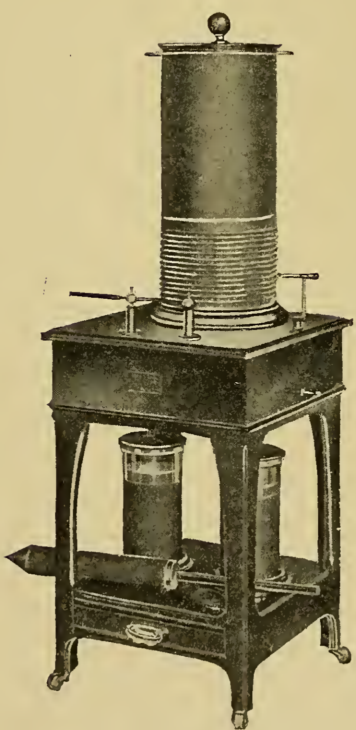
short circuit. No condenser is used, as the capacity of the coil itself is sufficient. Fig. 77 gives a diagram of the arrangement. One end of the resonator, indicated at R (the other letters having the same meaning

Fig. 77



D'Arsonval oscillator with resonator.

Fig. 78



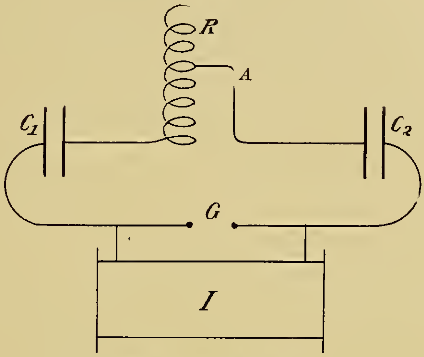
High frequency or Oudin resonator.

as before), is connected to a point on the main oscillating circuit; the other end is left free. If now the capacity and inductance of the resonator are such that it is in tune with the main circuit, the discharge

of the latter will excite oscillations of considerable amplitude in it, so that the free end will undergo alternations of potential sometimes much larger than those in the exciting circuit. This will become manifest by a powerful brush discharge which appears at this point.

For the maximum effect the frequencies of the two systems must correspond. Even when this correspondence is once attained, it will be

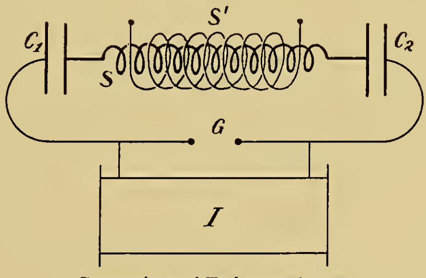
FIG. 79



Self-exciting resonator.

destroyed if the capacity of the resonator is altered by connecting it with any apparatus, or, as in medical treatment, with a patient. To make a readjustment possible, the connection with either the resonator or the solenoid is made adjustable so as to vary the length of the coil used. By thus altering the inductance, the frequency of one coil may be adjusted to that of the other. A small alteration of this adjustment will make a striking change in the amount of the discharge.

FIG. 80



Connections of Tesla transformer.

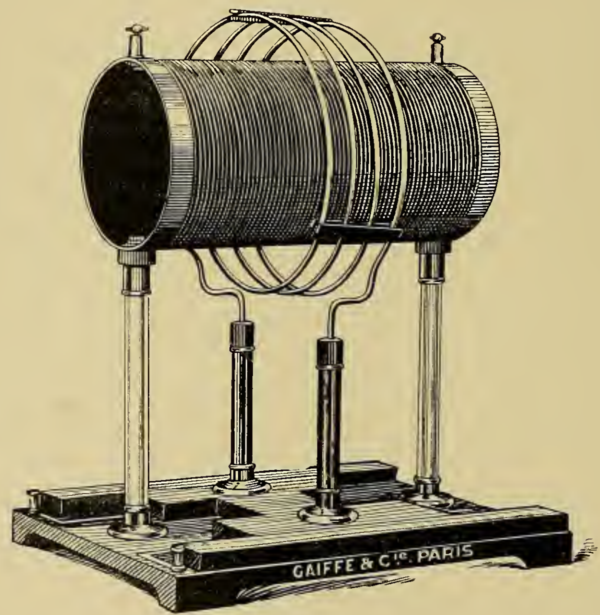
An apparatus used for producing high potential by resonance, usually known as an Oudin resonator, is shown in Fig. 78. In the lower part is seen the condenser, consisting of two Leyden jars, which, with the solenoid and spark-gap (not seen in the figure) comprise the primary oscillating circuit. Above is the resonator, wound on an insulating drum. The adjustable connection by which it is tuned may be

seen on the right. The upper free end of the resonator is terminated by a knob, to which an electrode may be attached by means of an insulated wire. (See also Figs. 163 and 165).

Sometimes the same coil is used both as exciter and resonator, and the other solenoid is dispensed with. The connections are then as in Fig. 79. The lower part of the coil is here included in the exciting circuit, while the upper part acts as a resonator. The connection with the condenser at A is made adjustable for the purpose of tuning.

The High Frequency Transformer.—If a secondary coil is added to the solenoid of a high frequency oscillator, as S' in Fig. 80, the apparatus becomes a high frequency transformer, sometimes called a Tesla transformer. Fig. 81 shows one form of the apparatus. The secondary coil, consisting of five or six times as many turns as the primary coil, is here placed inside the latter. It is often immersed in oil to improve the insulation.

Fig. 81



Tesla transformer.

The oscillations through the primary coil induce synchronous oscillations in the secondary. These, however, will not reach their maximum amplitude unless the secondary coil is in resonance with the primary circuit. In fact, from another point of view, the secondary may be regarded as a resonator excited by induction instead of by direct connection with the oscillator. The inductance of the primary circuit should therefore be adjustable in the manner described above (p. 102) in treating of the resonator.

SECTION II

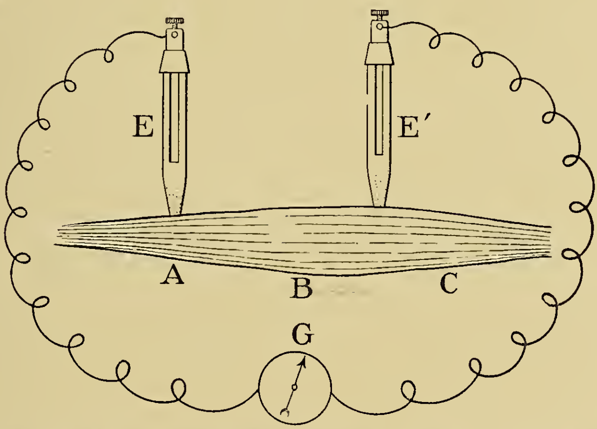
ELECTROPHYSIOLOGY

CHAPTER V

ANIMAL ELECTRICITY

THE fact that animal tissues can produce an electric current was first demonstrated by Galvani in 1793. By laying the exposed muscles of the leg of a frog upon a glass plate and touching them with the end of

FIG. 82



Scheme to illustrate the action current of a simple muscular contraction. *A*, *B*, *C*, a piece of muscle, *E*, *E′*, electrodes connected by a wire to a galvanometer, *G*. Stimulation of the muscle at *A* causes a wave of contraction to begin at this point and this electrode becomes negative to *E′*, which is positive, and the needle *G* shows a corresponding variation. When the wave of contraction reaches the middle point *B*, the potential of *A* and *B* now being the same, no current passes and the needle returns to the zero point. The wave now passes toward *C*, which in turn becomes negative to *A*, and the needle is deflected in the opposite direction. (James.)

the sciatic nerve which had previously been dissected out and cut off close to the spinal cord, he caused contraction of the muscles. Volta however, denied that the electricity was produced by the tissues, and claimed that it was due to the contact of dissimilar fluids and tissues.

This view was held until 1841, when Du Bois Reymond began his famous investigations. He showed that all muscles and nerves are the seat of electric currents. He claimed that an electric current exists in normal resting muscle, which he called "the current of rest." In other words, the human body may be considered to be a battery, the poles of which are the limbs, and if two of the limbs are placed in vessels containing salt solution and connected by a wire a constant current is generated (the rest current), which can be demonstrated by a very sensitive galvanometer. This current is due to the difference of potential between any two parts of the body, and is not dependent upon muscle contraction. Du Bois Reymond further showed that contraction of a living muscle also produced a current, termed the "current of action;" in other words, a contracting muscle is a galvanic cell (p. 54), in which the active part corresponds to the zinc plate and the passive to the copper. Therefore the surface of that portion of the muscle which is active is negative to the rest of the surface which is positive (Fig. 82). If all other muscles are kept at rest and electrodes placed upon the surface of the body, electrical changes produced by the contraction of the heart muscle can be demonstrated. This was first done in 1856 by Kölliker and Müller in frogs, and in 1887 Waller demonstrated it in the human subject. Lately these facts have become of practical value in diagnosis owing to the perfection of an exceedingly sensitive galvanometer by Einthoven, of Leyden, by means of which tracings of these changes can be made. These have been termed electrocardiograms (see p. 180).

CHAPTER VI

THE HUMAN BODY AS A CONDUCTOR OF ELECTRICITY

RESISTANCE AND CONDUCTION

Of much more importance than the phenomena mentioned in the preceding chapter are those attending the passage of a current produced outside the body through the body. All of the tissues of the body will act as conductors of electricity, but they all do not conduct equally well, as some offer more resistance to the current than others. As the amount of resistance depends upon the amount of water and salts that the tissue contains, those containing little of these elements, as the dry epidermis and its congeners, the hair and horny structures, are very poor conductors—in fact, the worst—while those which contain considerable, as the muscles and nervous elements, are the best. In the order of their efficiency the different tissues of the body may be ranked as follows: Nervous elements, muscles, fat, muscle sheaths, tendon, cartilage, bone, dry epidermis, hair, and horny structures.

Widely divergent figures have been given by different observers as the resistance of the body, they ranging from 1000 to 200,000 ohms. These variations are due to the parts tested and the methods of making the tests. Stone (Lumleian Lectures, 1886) found the average resistance from foot to hand or from foot to foot to be 1000 ohms. The contacts were made by plunging the extremities into large bowls of salt water. The dry epidermis, especially if it is horny or calloused, as on the soles of the feet or palms of the hands, offers a much higher resistance than this. The amount of resistance is influenced by the following, all of which should be remembered as they are of practical importance in using the current for diagnosis and treatment.[1]

1. The condition of the skin, if thick or thin, dry or moist, cold or warm. Thus, parts not habitually exposed offer less resistance than those which are. Consequently parts of the body usually covered by clothing give less resistance than those which are not, as, for instance, the hands, especially the palms. An exception to this is the soles of the feet, which are usually covered by a thick, horny layer of epithelium. Moist skin offers much less resistance than dry skin, hence when it is desired to have the current pass through the skin it should be moistened, preferably with a warm saline solution, as warm skin is less resistant

[1] The following statements in this chapter, unless otherwise specified, refers more particularly to the constant current than to other forms.

than cold and a salt solution is less than plain water, as it affords an abundance of ions to carry the current (see Electrolysis, p. 49).

2. The area of the electrodes and the pressure with which they are brought into contact with the body. The amount of resistance is inversely as the size of the electrode, hence the greater its area the less the resistance; also the firmer the pressure the less the resistance.

3. The E. M. F. of the modality used. The greater this force the less the resistance, for this reason there is less to faradic and static electricity than to galvanic, as they have a very high E. M. F.

4. The duration of the current flow. The resistance diminishes as the current passes through the skin for the following reasons: The skin is rendered hyperemic, the local temperature rises, and perspiration increases, hence the skin becomes more moist. Owing to this fact it will be found that a strength of current which at first is well borne may in a little while become too strong for the patient to bear.

5. The greater the distance the current has to traverse the greater the resistance, hence when it is desired to diminish the resistance the electrodes should be placed comparatively close together. This, however, should not be done when it is desired to obtain a pure polar action (p. 111).

6. The resistance of the body is also influenced by some pathological conditions, which will be considered under electrodiagnosis (p. 178). (See also Section I, Chapter II.)

Measurement of the Resistance of the Body.—Owing to the fact that some diseased conditions diminish the body resistance, it is of some importance to know how it may be measured. This can be done either by the use of the Wheatstone bridge, by the substitution method, or by the use of Ohm's law (p. 42).

In order to carry out the second method, a galvanic battery with a dead beat galvanometer and a rheostat that can be thrown into the circuit, are all that is necessary; it is therefore the more convenient for the practitioner. It is also preferable, as with it we obtain results which represent the constant minimum, while with the Wheatstone bridge the initial or higher resistance only is determined. The substitution methods will therefore alone be described; it is carried out as follows:

The body or that part of the body whose resistance it is desired to measure is placed in the circuit between two well-moistened electrodes. The current (constant) is then started, increased, and allowed to flow long enough until the meter shows a certain constant strength, for instance, 5 milliamperes. The body is then removed from the circuit and a measuring rheostat placed in the circuit, by means of which a resistance of more than 10,000 ohms is interposed. The electrodes are then placed in contact with each other and by means of the rheostat resistance is added or thrown out until the meter shows 5 milliamperes of current. The amount of resistance necessary to do this is the resistance of the body or part of the body being measured.

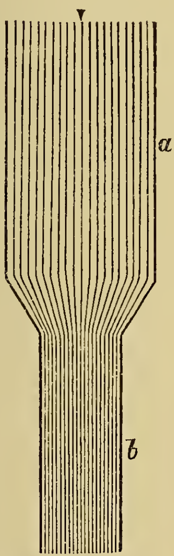
The third method depends on a knowledge of the electromotive force of the cells used and the galvanometer reading. Jones[1] illustrates it as follows: If twelve Leclanché cells in good condition are used to generate the current used, the E. M. F. will be 18 volts, and if the current passing through the patient as shown by the galvanometer be 4 milliamperes, the resistance may be calculated as follows: R = resistance, C = current strength, E = electromotive force; then

$$R = \frac{2}{C} \text{ or } R = \frac{18}{0.004} = 4500 \text{ ohms}$$

which would be approximately the resistance.

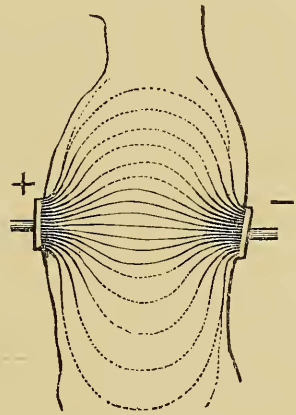
Density and Diffusion of the Current.—The physiological action of the current depends not alone upon its strength, but also upon its density. This is greater in proportion as the area of the conductor is smaller. Fig. 83, from Erb, illustrates how this is so. He, for illustration, considers the current to be composed of a certain number of threads, the greater the number of threads the stronger the current, and the greater the number of threads which are compressed into a certain area, the greater is the density of the current. Thus, to still further employ his

FIG. 83



Schematic representation of varying density of the current, its strength remaining the same; the same number of threads of current in part *b* of the conductor compressed into half the area of the part *a*; the density in *b* is therefore twice as great as in *a*. (Erb.)

FIG. 84

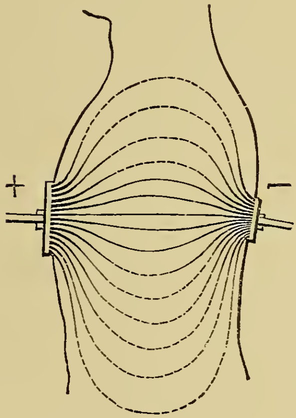


Schematic representation of the distribution and density of the current with two electrodes of equal size; the density beneath them is equal. (Erb.)

[1]Medical Electricity, fourth edition.

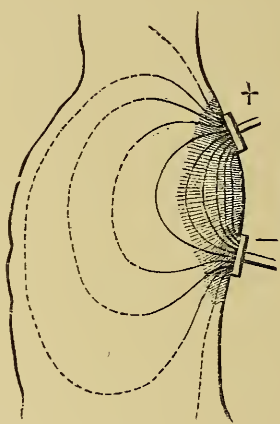
illustration, if you imagine a current composed of one thousand threads carried through a conductor 1 sq. cm. in transverse section, and then through one that has an area of 2 sq. cm., the one thousand threads in the latter case will be spread over twice as great an area as in the former, and the density accordingly would be only half as much. While the current would possess the same strength in each case, it would not be as concentrated, and hence, if it is desired to concentrate the current upon a small area of the body, a small electrode should be used, for, as has just been shown, it does not receive as much current from a large electrode as from a small one (Fig. 85). The effectiveness of the current as a stimulant to nerve action depends largely upon the greatness of its density.

Fig. 85



Schematic representation of the density of the current with electrodes of different sizes, the An twice as large as the Ca; the density beneath the Ca is twice as great as beneath the An. (Erb.)

Fig. 86



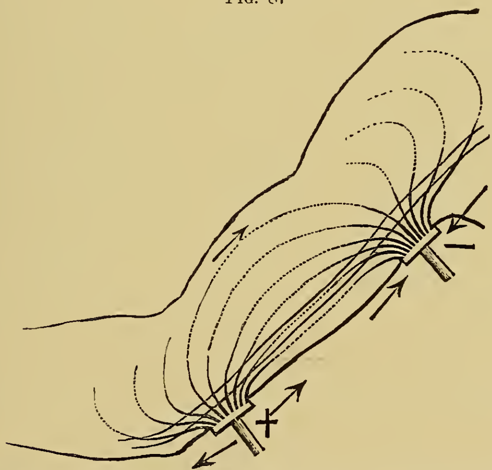
Schematic representation of the density of the current upon application of the electrodes to the same surface, close to one another. Ineffective threads of current are dotted. Zone of greatest density is shaded. (Erb.)

As has been already shown, the human body is electrically made up of a number of conductors of different ability, the current, therefore, when it enters the body does not flow in a direct line from one electrode to the other, but diffuses itself more or less through the body, as is shown in Figs. 84 and 85. Only those tissues which are immediately under and comprised in the shortest path between the two electrodes will experience physiological action of the current of any consequence. This is due to two reasons: (1) The strength of the current is inversely as the resistance, and the greater the distance it travels the greater, of course, is the resistance (p. 45), so that the current strength of the long loops (Fig. 86) will become too weak to exercise any influence. For this reason also, unless the poles are close together, the current will soon become so weak as to have little influence even in the region in a direct

line between the electrodes (Fig. 87). (2) The density of the current is inversely as the sectional area of the path of the current, therefore in that part of the body where the current is considerably spread out it will not be great enough to produce any effect (Fig. 85). A knowledge of these facts is of great practical importance when we wish to bring certain parts or organs under the influence of the current (see p. 201), and also in causing us to remember that owing to current diffusion, parts may be influenced by the current, when used either for purposes of diagnosis or therapeutically, that are some distance from those being examined or treated (see p. 205).

Current Direction and Polar Action.—If the electrodes could be placed upon an isolated muscle or nerve, the current would flow directly from the positive, or anode, to the negative pole, or kathode, and would either be ascending or descending according to the arrangement of the poles. In the human body this never takes place, as, owing to the diffusion of the current above described, after the current has passed through the skin and other tissues overlying the muscle or nerve it will be flowing in several directions. Thus, in Fig. 87 it will be seen

Fig. 87



Schematic representation of the effective threads of current in the ordinary percutaneous application of both electrodes to a nerve (ulnar nerve in the arm). The ineffective threads of current are dotted. There are four different directions of the current in the nerve. (Erb.)

that only part of the current flows directly along the nerve from one pole to the other, another part flows through it perpendicularly, and other parts pass through it in the opposite direction. Therefore, current direction cannot enter into the use of electricity for either diagnostic or therapeutic purposes. It must also be remembered that there is a distinction between the physical and physiological anode and kathode.[1]

[1] These facts only apply to the constant or galvanic current, this being the only form of current possessing marked polar action.

Thus, if we are applying electricity to a nerve, the former would be where the poles of the battery are placed in contact with the skin over it, the physiological anode, or, as it is termed, the virtual anode, on the other hand, will be where the current enters the nerve and the physiological or virtual kathode will be where the current leaves it. There is thus a virtual anode at every point where the current enters the nerve and a virtual kathode wherever it leaves it. The proximal part of the nerve, *i. e.*, where the current enters it at the anode and leaves it at the kathode, is termed the *polar zone*, or region. The distal part, *i. e.*, where the current leaves the nerve at the anode and enters at the kathode, is known as the peripolar region (Fig. 88). It will be seen by reference to

Fig. 88

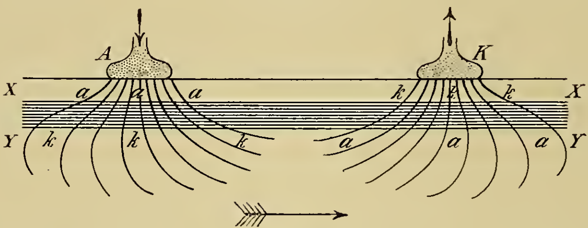


Diagram showing physical and physiological anodes and kathodes: *A*, the physical anode, or positive electrode; *K*, the physical kathode, or negative electrode; *a*, *a*, *a*, physiological anodes; *k*, *k*, *k*, physiological kathodes. *X X*, polar region; *Y Y*, peripolar region. (Howell.)

Fig. 87 that owing to the diffusion of the current its density at the virtual anode is greater immediately under the physical anode and at the virtual kathode immediately under the physical kathode. Therefore, while we have some influence exerted by the opposite pole at these respective points, the dominant action will be exerted by that pole whose density is greatest. Upon these facts depend the laws of contraction and polar action hereafter to be described (pp. 115 to 120).

PHENOMENA ATTENDING THE PASSAGE OF THE ELECTRIC CURRENT THROUGH THE LIVING BODY

These phenomena may be divided into (1) those which may occur both in living animal tissues and in inorganic and inanimate structures; these comprise *electrolysis* and *phoresis*, divided into ana- and cataphoresis, and (2) those that are peculiar to living animal tissue and comprise *electrotonic effects; excitation* and *muscle contraction;* influences upon *circulation* and *metabolism* and *bactericidal action*. As an understanding of both electrolysis and phoresis is necessary to understand some of the changes mentioned in the second division, they are described first. It is important also to remember that all of these phenomena are not produced equally well by all forms of current, *i. e.*, galvanic, faradic, sinusoidal, static, and those of high frequency, the first mentioned being the only one that will cause all of them (pp. 77 and 138).

ELECTROLYSIS

A description of the phenomenon of electrolysis as applied to inorganic substances will be found on pages 48 to 51. As the various tissues of the body are more or less saturated with fluid in which various salts are in solution, it also must be regarded as an electrolyte. It therefore conducts the electrical current as similar chemical combinations do elsewhere, that is, by causing electrolytic decomposition. The tissues of the body being so complex in their structure, a large number of decompositions and recombinations take place (p. 50), which are most manifest where the electrodes are in contact with the body, but also take place more or less in the interpolar region (p. 133). A large part of the therapeutic action of the galvanic current especially depends upon this action. Stewart[1] has observed that practically the whole of conduction in animal tissue is electrolytic, and that the electrolytes are chiefly the inorganic constituents, the changes in the proteids being brought about by secondary actions (p. 133). He did not find that hemoglobin acts as an ion. He further states that there are four ways in which electrolysis can affect, in the living body, such tissue as muscle: (1) By the chemical effects of the products liberated at the electrodes or in the substance of the tissues; (2) by the removal of electrolytes, chiefly inorganic substances which are necessary for the vitality of the tissues leading to increased absorption of the elements, and, perhaps in consequence, to increased activity of the general nutrition in the tissue, or if the action be more intense, to diminished vitality, degeneration, and death; (3) by cataphoresis (p. 114), leading to increase of transferred substances around the kathode, and diminution around the anode and the consequent increase of eliminating or absorbing activity, by which a tissue returns to healthy equilibrium, or to any of the results which follow the disturbance of equilibrium beyond the limits of health; (4) by raising the local temperature in both cases, but the physiological change may be very different.

In general, it may be said that oxygen and acids will appear at the anode and hydrogen and alkalies at the kathode. This may be shown by using uncovered metallic electrodes on the skin, when, if the current is strong enough, vesicles will form, that at the anode containing an acid fluid, and that at the kathode an alkaline; the former, also, unless composed of platinum, will be tarnished and corroded by oxidation. If a current is passed through blood, coagulation is produced at each pole. At the anode the clot is firm, small, and of an acid reaction, while at the kathode it is larger, looser in texture, frothy, and alkaline. This action of the anode has been utilized in the treatment of aneurysm and vascular skin growths. If the current is passed through muscle or fibrous tissue by means of electrodes consisting of needles introduced

[1] Electrolysis of Animal Tissues, Lancet, December 13, 1890

into the tissue, it will be found that at the anode the parts are dried, hardened, and stick to the needle, due to the acid produced, while at the kathode they are softened and liquefied. Hydrogen is given off, as evidenced by frothing, and the needle is loose. This action of the kathode has been utilized for the destruction of small growths, tumors, etc. (p. 267). It is probable that the strong currents which have been employed by Apostoli, Massey, and others for the destruction of uterine fibroids, in addition to the polar action, act by setting up retrogressive and disintegratory changes in the interpolar region. Similar changes due probably to electrolysis in this region may also be caused by milder currents applied over the skin (5 to 20 milliamperes), as is shown by the absorption of fibrous bands and adhesions which may follow inflammation of joints. The sinusoidal current also possesses some electrolytic action. This is greater when the alternations are slow. It is possible also that high frequency currents possess some of this power.

PHORESIS

The breaking up of an electrolyte into its constituent ions by the electrolytic action of the galvanic current produces also another phenomenon, that of *phoresis*. This has been described on page 50. The electropositive ions moving toward the kathode causes what is known as *cataphoresis*, and the movement of electronegative ions toward the positive pole is termed *anaphoresis*. In addition, the property of osmosis, by which ordinarily a liquid of lighter density will flow through a porous partition to one of greater, is to a certain degree reversed by the passage of a constant current. In other words, if the anode is placed in the receptacle containing one liquid and the kathode in the other, the liquid will flow through the partition in the direction of the current no matter what the density. This property also takes part in the phenomenon of phoresis and the changes in the body produced by it.

While this phenomenon is, to a large extent, due to some mechanical actions not understood, and that all salts in solution may be diffused from the anode, it is also certain that diffusion is partly due to electrolytic action and the consequent migration of ions. It is certain that considerable of the therapeutic action of the galvanic current is due to this action, it causing a direct transference of the fluids and salts of the body by way of cell walls, muscle septa, coats of bloodvessels, serous and mucous membranes, etc., and consequently together with electrolysis, which acts chemically, it mechanically alters the amount and distribution of salts necessary to the proper nutrition and function of the various parts of the living organism. Primarily this action takes place throughout the tissues situated between the electrodes, but secondarily its influence is felt beyond the interpolar region.[1] It has been observed through the microscope that when muscle is subjected

[1] Cleaves, Journal of Advanced Therapeutics, December, 1908, p. 643 et seq.

to a constant current, a visible flowing of its juices from the anode to the kathode takes place and a swelling of the negative end is produced.

By the properties of electrolysis and phoresis, therefore, can the amount of blood, fluids, and salts either be increased or diminished in a part, and consequently either nutrition improved or diminished, this latter power being employed to remove exudates and destroy growths (p. 132). Some cataphoric action is also possessed by the *sinusoidal* current if the alternations are slow. It has been demonstrated by Burch[1] that *high potential* and *high frequency currents* have some power of causing solutions to pass through the skin. He found that by painting an area of skin with an oily solution of iodine and then applying over it a vacuum electrode attached to one of the terminals of a Tesla coil, he could obtain a marked reaction of iodine in the saliva, and that this was more marked when the high frequency current was so employed than when the iodine was painted upon the skin and no electricity used (see p. 277). The practical application of these phenomena will be discussed on pages 267 to 277.

ACTION OF GALVANIC CURRENT UPON MOTOR NERVES AND MUSCLES

Electrotonus.—It has been found that if a constant or galvanic current be passed through a nerve a change in its excitability and conductivity occurs whereby the functions of the nerve are either decreased or increased, according to the direction and strength of the current.

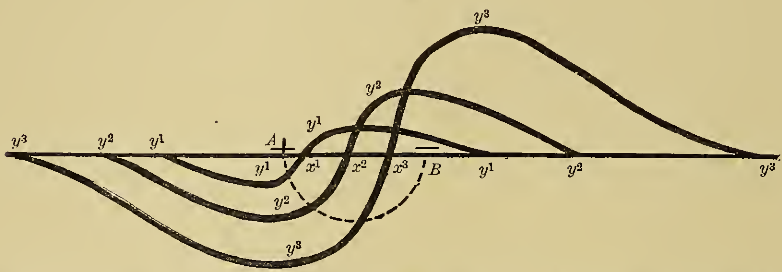
Pflüger formulated these changes as follows: If any portion of a nerve be traversed by a descending or ascending constant current, the excitability of the intrapolar as well as the extrapolar regions undergoes a change which, upon investigation, is found to be decreased in the neighborhood of the anode, and increased in the neighborhood of the kathode. These changes have been termed the electrotonic alterations of nerve excitability, or *electrotonus;* the zone of diminished excitability is said to be in a condition of anelectrotonus, the zone of increased excitability to be in a condition of katelectrotonus. Each of these zones extends for some distance on each side of the pole. Between the electrodes there is a point at which the anelectrotonic and katelectrotonic states merge into each other, and the normal condition of the nerve is preserved. This is termed the neutral point. The degree to which these changes may be manifested and the extent of nerve involved depends upon the strength of the current employed, they becoming more marked as the current is made stronger. The stronger the current the further will the neutral point advance toward the kathode, and thus, if a weak current is employed, the larger portion of the intrapolar region is katelectrotonic; if a very strong current is used, the larger portion is anelectrotonic (Fig. 89). As the excitability is lessened, so the con-

[1] Journal of Advanced Therapeutics, December, 1905, p. 726 et seq.

ductivity of the nerve is lessened in the neighborhood of the anode, while the reverse occurs in the region of the kathode. The positive and negative modifications also occur (see below).

When the circuit is opened further changes occur. After this is done the normal condition is not at once rëestablished, the length of time required being proportional to the strength and duration of the current, requiring accordingly from a few seconds to several minutes. In the region of the anode there will be a brief period in which the excitability is increased, termed by Pflüger the positive modification, after which the nerve resumes the normal condition. At the kathode there is first a brief period of lessened excitability, the negative modification, after which a further condition of increased excitability (positive modification) is undergone, lasting a variable period of time (from one

Fig. 89



Electrotonic alterations of irritability caused by weak, medium, and strong battery currents; *A* and *B* indicate the points of application of the electrodes to the nerve, *A* being the anode, *B* the kathode. The horizontal line represents the nerve at normal irritability; the curved lines illustrate how the irritability is altered at different parts of the nerve with currents of different strengths. Curve y^1 shows the effect of a weak current, the part below the line indicating decreased, and that above the line increased irritability, at x^1 the curve crosses the line, this being the indifferent point at which the katelectrotonic effects are compensated for by anelectrotonic effects; y^2 gives the effect of a stronger current, and y^3 of a still stronger current. As the strength of the current is increased the effect becomes greater and extends farther into the extrapolar regions. In the intrapolar region the indifferent point is seen to advance with increasing strengths of current from the anode toward the kathode. (Howell.)

to fifteen minutes); as this passes off the nerve resumes its normal state. If the electrodes are placed over a muscle instead of the nerve, the excitability of the muscle is similarly increased or decreased according to the pole employed. This is due to the intramuscle nerve ending being thrown into the electrotonic state.

The whole cycle of change due to the passage of a current may be summed up as follows:[1]

Closure.	Cessation.
Anodic fall of excitability (*i. e.*, greater stability of molecular equilibrium), established instantaneously, increasing slowly to a maximum, and slowly declining.	Auodic rise of excitability (rebound to lessened stability), established instantaneously, increasing, and subsiding slowly.
Kathodic rise of excitability (*i. e.*, less stable molecular equilibrium), established instantaneously, increasing rapidly to a maximum, and subsiding quickly.	Kathodic fall of excitability (rebound to greater stability), established instantaneously and subsiding rapidly.

[1] Text-book of Physiology, edited by Schäfer, ii, 498.

The description above given applies to the exposed nerve and muscle. When the current is employed for either therapeutic or diagnostic purposes in the human subject, owing to these tissues being covered by the skin and other overlying structures, the changes just described are not so intense, but they occur. The diminution being due to the phenomena of current diffusion and formation of virtual poles (p. 112).

Excitation and the Laws of Muscle Contraction.—It is well known that an electric current passing through a muscle or nerve will, under proper conditions, excite them to activity which in the case of a motor nerve or muscle is manifested by a muscular contraction. The conditions necessary to produce this phenomenon were first formulated by Du Bois Reymond as follows: "The absolute amount of density of the current at any certain moment does not act as a stimulant to the motor nerves, but merely the change in its amount from one moment to another, *i. e.*, only the variations in the density; these act the more powerfully the greater they are in a unit of time, or, their amount being equal, the more rapidly they occur; most powerfully, therefore, upon a *sudden closure* or *opening* of the circuit. In other words, neither the mere passage of a constant current through a motor nerve, nor a gradual variation of its strength excites it to activity, but this is only accomplished by a *sudden* increase or decrease in the current strength. Comparatively recent observations have shown that the law as stated above is not strictly correct, and that when the changes of density are made above a certain rate of rapidity, which is exceedingly high, no contraction takes place even with exceedingly great voltage. This is seen in the use of the so-called currents of high frequency (pp. 122 and 126). There is, therefore, not only a necessity for sudden changes in current density to excite a motor nerve to action, but that these changes be not made with an excessive rapidity. Du Bois Reymond also stated that excitation with the constant current was probably nothing more than the first stage of electrolysis in excitable tissue. This view is still held (p. 112).

It has been found that in the case of the constant current the same amount of contraction is not produced when the circuit is either opened or closed, that variations made with a weak current do not act similarly to those made with stronger ones, and that the direction in which the current flows through the nerve, *i. e.*, whether ascending or descending,[1] makes a difference in the result. The phenomena resulting from these various conditions have been formulated by Pflüger in the following law, known as Pflüger's law of contraction: With weak currents flowing in either direction, a contraction is caused on closing the circuit and none in opening it. That obtained on closure of the ascending current is somewhat stronger than that of the descending. With currents of moderate strength, contractions occur both on opening and closing in either direction. The former are weaker than the latter.

[1] By an ascending current is here meant one which flows through the nerve away from the muscle, and by a descending current one which flows toward the muscle (Fig. 90).

With very strong currents (such as are never employed upon human beings) a contraction occurs on opening of the ascending current and none on closing, while just the reverse occurs with the descending.

These phenomena, when tabulated, appear as follows:

PFLÜGER'S LAW OF CONTRACTION

Current Intensity.	Ascending Current.		Descending Current.	
	Closing.	Opening.	Closing.	Opening.
Weak	Weak contraction	Rest	Weak contraction	Rest
Medium	Strong contraction	Weak contraction	Strong contraction	Weak contraction
Strong	Rest	Strong contraction	Strong contraction	Rest

To understand this law we must bear in mind the laws of Du Bois Reymond (p. 117) and electrotonus (p. 115). The phenomena caused by either weak or medium strength currents are dependent upon the circumstance that at closure there is a sudden increase of irritability at the kathode (katelectrotonus), at which point the nerve is excited, while at opening the excitation takes place at the anode and is associated again with a sudden increase of irritability (positive modification).

FIG. 90

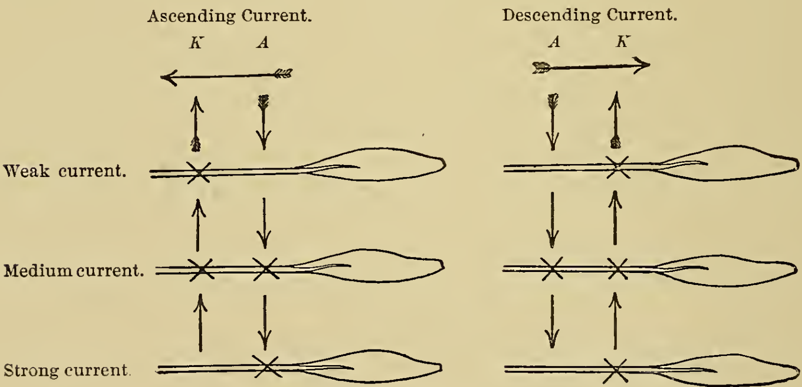


Diagram illustrating Pflüger's law. (Howell.)

The increase of irritability at closure (kathode) is greater than at opening (anode), and therefore the former produces contraction with weaker currents than the latter. The effects produced by strong currents are due to similar excitation modified by the polar interferences with conductivity (p. 115). Thus the nerve is excited as above described, only to a greater extent, but in the case of motor nerves the irritation on closure in the case of ascending currents has to traverse that portion of the nerve that is in a state of anelectrotonus or lessened conductivity

from contact with the anode. This area acts as a block, as it were, and so diminishes the intensity that it is unable to cause contraction.

When opened, the sudden increase of irritability (positive modification) causes contraction. When descending currents are employed closure causes contraction by the sudden production of katelectrotonus, while the excitation started by the anode on opening has to traverse that portion of the nerve in which katelectrotonus is disappearing (negative modification), and in which, consequently, conductivity is diminished. Hence there is either no or a very slight contraction. The passage of strong currents may cause a continuous contraction, which in the case of cessation of the ascending current is known as Ritter's opening tetanus. At closure of the descending current it also occurs, but is not so marked.

The Laws of Contraction as Varied by the Previous Passage of the Current through other Tissues before Reaching the Nerve.—Pflüger's laws were based upon experiments on the isolated nerve of the frog. The results obtained by the application of the poles over the course of a nerve in the human subject, covered as it is by various tissues of different degrees of conductivity (p. 107), are not exactly identical, but, as in the case of electrotonic changes (p. 115), they correspond nearly enough to be of practical use. As it is impossible to confine the current to the trunk of a nerve when it is covered by other tissues (Fig. 87), we cannot speak of either ascending or descending currents. We can, however, study the effects of a pole placed over the nerve separately, while the other pole is placed on some other distant point of the body. This is known as the polar method. To understand the phenomena thus produced it is necessary to remember three facts, viz.:

"1. At the moment a battery current is closed an irritating process is developed at the physiological kathode, and when it is opened, at the physiological anode.

"2. The irritating process developed at the kathode at the closing of the current is stronger than that developed at the anode at the opening of the current.

"3. The effect of the current is greatest where its density is greatest."[1]

In other words, the excitation occurs where the current is leaving the excitable tissue (Fig. 88). Hence closure of the circuit causes a muscular contraction, termed the closing contraction, due to irritation at the physiological kathode, while opening of the circuit causes a contraction (opening contraction) due to irritation at the physiological anode. The degree of contraction is directly as the amount of irritation. As we have under each physical anode and kathode physiological anodes and kathodes (Fig. 88), four possible degrees of contraction may occur; viz., anodal closure, anodal opening, kathodal closure, kathodal opening. For convenience these have been designated respectively by the symbols AnCC, AnOC, KCC, KOC.

[1] American Text-book of Physiology, first edition, p. 63.

As kathode may also be spelled c-a-t-h-o-d-e, the symbol Ca may be used instead of K. The different degrees of strength of the contraction may be designated as follows: KCC, a stronger KCC by KCC′, still stronger by KCC″, and so on. If the contraction is so strong that it is tetanic in character, it may be designated KCTe or AnCTe, as the case may be. Instead of C for closure, Cl is sometimes used. With the weakest current that will cause a contraction, we find KCC appearing first, a little stronger current will cause AnCC, still stronger AnOC, and finally, with very strong currents, KOC can be developed. These may be tabulated thus:

Weak current	KCC
Moderate current	KCC′, AnCC, AnOC
Strong current	KCC″, AnCC, AnOC, KOC

Sometimes, owing to the nature of the tissues that cover the nerve, causing the current density at the physiological anode to become greater than at the physiological kathode, AnOC may appear before AnCC The reason for this order will be readily understood by reference to Fig. 88 and the following table:[1]

In the	The nature of stimulus is	The situation of stimulus is		
KCC	Kathodic	Polar	=	Best stimulus in best region.
AnCC	Kathodic	Peripolar	=	Best stimulus in worst region.
AnOC	Anodic	Polar	=	Worst stimulus in best region.
KOC	Anodic	Peripolar	=	Worst stimulus in worst region.

Thus, in the case of the KCC it will be seen that the greatest density of the current is at the physiological kathode, consequently the irritating effect of the production of katelectrotonus is marked (see Electrotonus and Current Density), while in the case of AnCC the greatest density of the current is at the physiological anode, consequently the irritating influence of the kathode is modified by this and the production of anelectrotonus (negative modification). As has been stated above (p. 117), the irritation produced by opening is not near so great as that by closing the circuit; hence, while at the physiological anode the current density is greater, the irritation is still not so great as that produced by the physiological kathode at this point, while in the case of KOC the current density is less at the physiological anode.

VOLTAIC ALTERNATIVES

A still greater irritation of the nerve, and hence a stronger contraction, can be produced if, after the circuit has been closed for some time in one direction, it is closed in the opposite, *i. e.*, if the circuit is closed with the kathode over the nerve we reverse the current, making the

[1] Waller, quoted by Brubaker, International System of Electrotherapeutics, second edition, p. 128.

same pole the anode, and *vice versa*. This phenomenon is known as Volta's alternatives. It is due to the summation of the irritating effect of the anode (positive modification) and of the kathode (appearance of katelectrotonus), at one part of the nerve. This being a greater change in density than merely the disappearance of anelectrotonus (positive modification) or the appearance of katelectrotonus (Fig. 91).

FIG. 91

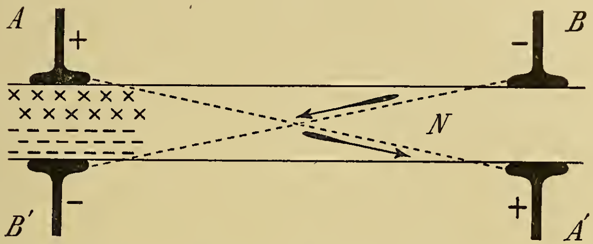


Diagram to explain Volta's alternatives: N represents a nerve trunk; A, the positive pole placed over the nerve; B, the negative pole at an indifferent point on the body. If the positive pole A, without moving it, is by means of a switch made the negative pole, represented by B', the negative pole B then becoming positive A', it will be seen that at A we will have a disappearance of anelectrotonus (positive modification), represented by $x\,x\,x$ plus the appearance of katelectrotonus, represented by ----. which is, of course, of greater irritating effect than either separately.

ACTION OF OTHER FORMS OF THE ELECTRIC CURRENT UPON MOTOR NERVES AND MUSCLES

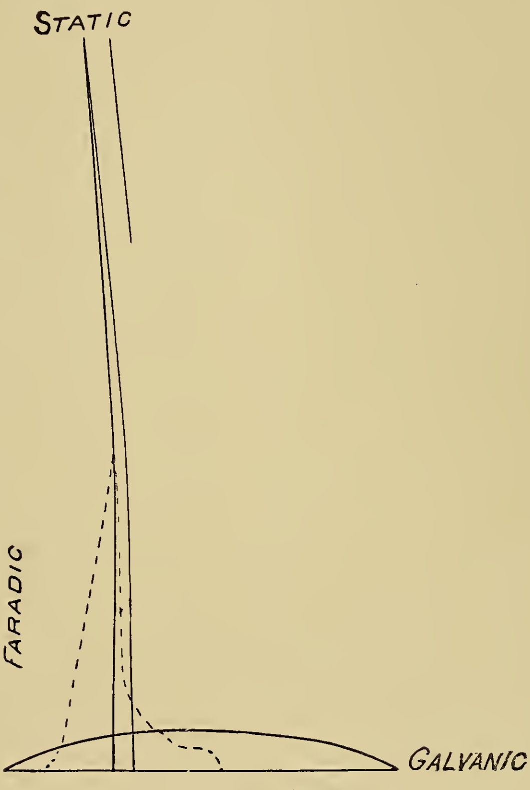
Faradic Current.—The laws of electrotonus do not apply to any but the galvanic current, but from the fact that the faradic current depends for its existence upon a sudden making and breaking of the circuit (p. 117), it is evident that marked and sudden changes in the current density are produced by it. Hence (p. 117), it is an effective agent for producing muscular contractions. This sudden variation in density is shown by Fig. 92. Accordingly, when this current is applied to a motor nerve, if strong enough, contractions occur in the muscles supplied by it. For the reason that the current of break, or demagnetization, is stronger, whether either the so-called extra current from the primary coil or the secondary coil is employed (p. 88 et seq.), its physiological action is greater; and hence the contraction produced when the circuit is opened is much greater than when it is closed. If the interruptions are made with sufficient rapidity, a tetanic contraction is produced, which persists so long as the current is passing, unless continued for a long time, when the muscle becomes exhausted and relaxation occurs.

Probably owing to its momentary duration, degenerated muscles are, however, not so easily stimulated to contraction by the faradic current as by the galvanic.

The physiological action of this current upon motor nerve and muscle is increased slightly by an increase in the rapidity of interruption up to

a certain speed, after which, if still further increased, its action is diminished until, if rapid enough, it ceases. Thus, according to Engelmann,[1] a moderate current, *i. e.*, the secondary coil covering $\frac{1}{3}$ of the primary, is sufficient to produce muscular contractions with 45 to 1000 interruptions a minute. This contraction grows stronger with an increase in the rapidity of interruption up to 4000 a minute; after this it begins to decrease, at 6500 the muscle practically ceasing to react. According to this same author, from 5 to 300 interruptions a minute produce the most effective muscular action.

FIG. 92



Current curves. (Engelmann.)

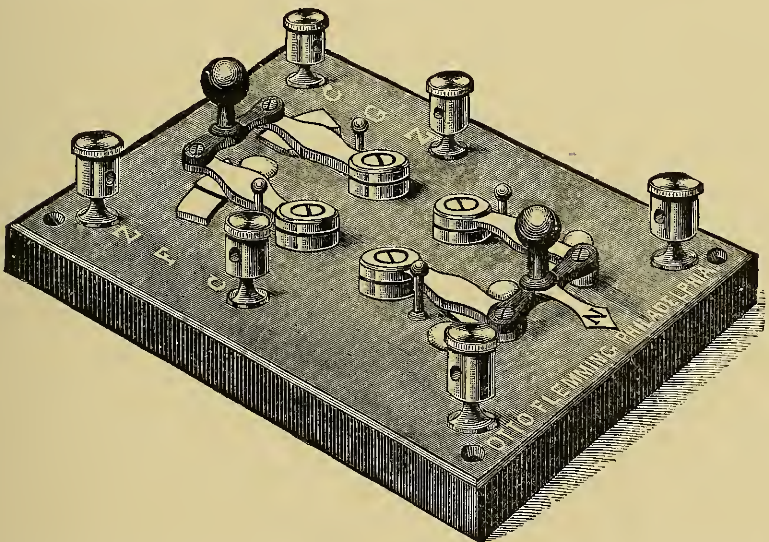
Debédat[2] has shown that the beneficial results from the use of this current are due to its gymnastic action, hence increasing the normal development of the muscle fibers. After a moderate use of the slowly interrupted current, histological examination showed an increased development of the active muscular elements, while after a prolonged

[1] International System of Electrotherapeutics, second edition, p. 211.
[2] Archives d'Electricité Médicale, 1894, p. 69.

tetanization, atrophy of the muscle fibers was found. If, however, a tetanizing contraction is continued for some time, relaxation or sedation takes place. This has been thought by some to be due to muscle fatigue, others[1] believe it to be due either to some sort of inhibitory action or to contracting the bloodvessels so that an anemic condition is produced in the nerve and muscle and hence impaired function.

It can be demonstrated that, as in the case of the galvanic current, the kathode is here also more efficient in producing contractions. Owing to the fact that the faradic current is an alternating current, it might be supposed that there is no constant positive and negative pole. When the current from the secondary coil is employed, this is the case, but the current of break is of greater intensity and hence greater physiological activity, and is the current meant when the polarity of the faradic current is considered. As the extra current from the primary coil, as as has been shown on page 90, practically only occurs at break, the same rule applies to it.

FIG. 93



De Watteville combiner, to which is added a polechanger or commutator, with index pointing to the negative pole.

Physiological Action of the Combined Galvanic and Faradic Currents.—The action of both currents may be obtained at the same time by means of a suitable switch (Fig. 93), or, if not at hand, by the following method: If the negative pole is to be attached to the indifferent electrode (p. 201) and the positive to the active, the negative cord of the galvanic battery is carried direct to the indifferent electrode and the positive cord of the galvanic current is carried to the negative post of the faradic battery.

[1] Journal of Advanced Therapeutics, November, 1909, p. 538 et seq.

To the positive pole of the faradic battery a cord is attached, which becomes the combined positive of both currents, and is to be carried through the meter and controller before reaching the patient. In short, it may be said that if the opposite poles of the two batteries are joined by a conducting cord, the unconnected poles of each battery become the combined poles of both. The tonic action of each is therefore accentuated, and muscular contractions are stronger than when the faradic current is used alone. This is explained by the facts that if the kathode is made the active electrode, increased excitability of the nerve is caused by the production of katelectrotonus (p. 115), and if the anode is made the active electrode, a virtual kathode (p. 112) is produced in the peripolar region around the anode, and this virtual kathode produces katelectrotonus.

This current is of much value in the treatment of motor paralysis, unstriated muscle is markedly influenced by it, and Rockwell claims that it has great efficacy in spasmodic affections.

Sinusoidal Current.—As this form is an alternating current, poles need not be considered; also, as the increase and decrease of intensity occurs more gradually (p. 78), muscular contractions produced by it are much less painful than those caused by currents in which the alternations are sudden, as the faradic (p. 122). To produce a contraction a certain frequency of alternation (at least 10 to 20 per second) is essential. With such a rapidity clonic contractions are produced. If this is increased up to a certain point (1000 to 2000 per second), the amount of contraction increases, 20 or over, causing it to become tetanic (as is the case with the faradic current). Above this point, however, no increase occurs, and if very rapid (10,000 per second), muscular contraction will cease. A great advantage of this form of current is that in addition to its causing very little if any pain, it has a marked contractile influence upon non-striated muscle. The best motor results are obtained with from 20 to 150 alternations per second (see also pp. 117 to 125).

Static Current.—When the spark from a static machine (p. 36) is directed to a muscle a contraction takes place. This has been found to be greater with the negative pole,[2] and is inversely in intensity to the size of the sphere upon the exciting electrode (Fig. 181). In other words, the smaller the ball the greater is the electric density (p. 109), and hence the greater the shock. If a very marked effect is desired, a pointed electrode (Fig. 192, *e*) should be used. The static current employed in the manner devised by Morton (static induced current, p. 231) will cause marked contractions, involuntary muscle fiber being influenced as well as voluntary. The static wave current will also cause muscular contractions (p. 135).

This power of causing muscular and tissue contraction is of therapeutic value in that where stasis or congestion is present it causes

[1] Resembling the action of high frequency currents.

[2] Bordier, Archiv. d'Electricité Médicale, 1898, p. 506.

expulsion of the fluid contents of the tissues and forces them in the direction of the vascular and lymphatic outlets, consequently removing inflammatory exudates (Snow). This action is greater from the negative side.

Currents of High Frequency.—These currents, meaning those of D'Arsonval, Tesla, and Oudin, as a rule, do not cause contraction of the muscles. D'Arsonval has advanced an hypothesis to explain this (p. 136). If, however, sparks are allowed to fall upon a motor point, muscular contractions may occur; especially is this so if the frequency is not very great. If, however, muscles are traversed by these currents for several minutes, a diminution of muscular excitability and relaxation occurs (myasthenia). This is more marked when the electrode is brought into immediate contact with the skin over the muscle (vacuum electrode) than when indirect methods are used (auto conduction).

ACTION OF THE ELECTRIC CURRENTS UPON SENSORY NERVES

Galvanic Current.—The application of the galvanic current to the sensory nerves of the skin will, if of sufficient strength, cause pain, as manifested in the case of mild currents by a feeling of warmth and prickling sensation, becoming more severe as the current is made stronger. The kathode seems to be more irritating than the anode, and the pain is of a burning character; under the anode the sensation is more like numbness. These sensations are probably in part due to the irritating chemical substances that are set free by the electrolytic action of the current (see Electrolysis).

A law of contraction has also been worked out for sensory nerves, the reflex contractions occurring in the muscles supplied by the irritated nerves being used to indicate the degree of sensory irritation. By this means it was found that the law is similar to that for motor nerves (p. 117), excepting when very strong currents were employed (third stage). It is then modified, owing to the fact that, as sensory excitation travels toward the central nervous system, it is the descending current which fails to produce the closing, and the ascending one which fails to evoke the opening effect.

Using the polar method (p. 120), Erb found that with a gradually increasing strength of current a brief KCl sensation first develops; this, as the current is increased, passes into a more severe prickling, whose intensity gradually diminishes if the circuit is not opened (kathode duration—KO); then follows a brief feeble sensation at AnO, followed later by a feeble AnC sensation, which, if the current is further increased, a more permanent sensation, as in the case of KCl, is developed, which gradually passes away (anode duration—AnO).

When very strong currents are employed, a weak KaO prickling may be obtained at the termination of KO. In the case of sensory nerves these laws have not been of any practical importance.

A muscular contraction produced by the galvanic current is attended by a sensation entirely distinct from that produced in the sensory nerves of the skin. It is caused by irritation of the intramuscular sensory nerves, and is a dull, tensile sensation, which increases as the strength of the current is increased until it may become actual pain. This is known as the *electromuscular sensibility.* As the conductivity of a nerve is diminished in the region of the anode (see Electrotonus, p. 115), the function of a sensory nerve, and hence pain, may be relieved by the application of this pole.

The nerves of special sense may also be irritated by the galvanic current. If passed in the neighborhood of the *optic nerves,* flashes of light appear as the circuit is opened and closed. Brenner has shown that this light is of different colors according to the pole used, and whether it is opened or closed.[1] By means of very strong currents the *auditory nerves* may be stimulated, as evidenced by different degrees of sound. Brenner (*loc. cit.*) states that with the kathode in the meatus closure of the current produces a marked sensation of sound, which remains during the passage of the current and ceases with its cessation. If the anode is employed only a slight noise is heard at the opening. These observations have not been confirmed by all observers. Alice Mackenzie[2] has used a different method, one electrode being applied over the tragus and the other held in the hand. Her subjects suffered from extreme degrees of deafness and tinnitus, and a current strength of four milliamperes was found to be the most successful. Her conclusions are as follows:

1. Subjective noises are increased on one side by applying the kathode to the ear; on the opposite side when the anode is in contact with the ear.
2. Increase of the subjective noises of the right ear occurred with the same strength of current when the kathode was applied to the right ear or when the anode was in contact with the left ear.
3. With the current of four milliamperes kathodal closure gives an increase of the subjective noises on the same side, and at the same time the noises in the opposite ear disappear.
4. With a current strength of four milliamperes kathodal opening increases the subjective noises only in the opposite ear.
5. Anodal closure affects the opposite ear, and anodal opening the ear on the same side.

In these cases much stronger currents were required to cause the nystagmus and vertigo described below, and from this she believes that the method may be used to determine whether the cochlear or vestibular nerve is the more degenerated; in her cases she believes the vestibular to be more so as a stronger current was required to produce reaction.

Important phenomena that have been utilized in diagnosis (p. 177)

[1] Handbook of Electrotherapeutics, Erb, p. 46 et seq.

[2] Wien. klin. Wochenschr., 1908, No. 11.

are the nystagmus and vertigo produced by galvanic stimulation of the auditory nerve. The practical value of these symptoms has lately been carefully studied among others by Neuman, Barany, and G. W. Mackenzie.[1] In brief, when one electrode is placed in front of the tragus, and the other at an indifferent point, as the current is gradually increased until it reaches 4 to 8 milliamperes the following will be observed. If the kathode is applied to the ear (*a*) rotary nystagmus to the side of the kathode; (*b*) sensation of the room rolling to the side of the kathode; (*c*) sensation of falling in the sagittal plane to the side of the kathode; (*d*) actual falling to the opposite side. When the anode is placed in the same location and a similar strength of current used, phenomena the reverse of those just mentioned occur. In normal individuals, if the technique[2] is correct, a similar strength of current should cause the kathodal and anodal responses. Mackenzie has indicated the reaction graphically as follows:

R. E. = right ear, L. E. = left ear.
Rot. R. = rotary nystagmus to patient's right.
Rot. L. = rotary nystagmus to patient's left.

R. E.	L. E.
K. 4 milliamperes, Rot. R.	K. 4 milliamperes, Rot. L.
An. 4 milliamperes, Rot. L.	An. 4 milliamperes, Rot. R.

Nystagmus is also caused at the opening and closing of the circuit. Closing the circuit with the kathode in front of the ear causes rotary nystagmus toward the side of the kathode; when the circuit is opened, movements lasting a few seconds are seen away from the side of the kathode. When the angle is employed the opposite occurs. In a normal person the reactions should balance, and may be represented graphically as follows:

K. C. N. = kathode closing nystagmus.
K. O. N. = kathode opening nystagmus.
A. C. N. = anodal closing nystagmus.
A. O. N. = anodal opening nystagmus.

R. E.	with 4 to 6 milliamperes	L. E.
K. C. N. = K. O. N.		K. C. N. = K. O. N.
A. C. N. = A. O. N.		A. C. N. = A. O. N.

According to Neuman these phenomena are due to influencing the nerve itself and not the nerve endings in the labyrinth.

Stimulation of the *gustatory nerves* produces an acid, metallic taste. It is claimed that the different poles produce different tastes; thus, if the anode is placed on the nape of the neck, the sensation is more marked, and is metallic and acid. If the kathode is so used, it is feebler, and is biting, salty, and alkaline. If the current is passed

[1] Archiv. Otologie, 1908, and Homeopathic Eye, Ear, and Throat Journal, April-May, 1910.
[2] The technique is detailed more fully on p. 178.

transversely through the cheeks, these differences may be simultaneously perceived.

The passage of strong currents into the nasal cavity, it is stated by Althaus, produces a phosphorus-like odor.

Faradic Currents.—Each passage of the faradic current is, if slowly interrupted (1 or 2 times per second), attended by a sharp, somewhat stinging and jarring sensation, which increases as strength of the current is increased. When the interruptions are rapid enough to tetanize muscle, the sensation consists of a prickling, which may, if the current is strong enough, become painful. If a sensory nerve is directly irritated, this sensation is felt in its entire area of distribution. If the stimulation is continued a numb sensation is added to the prickling. The painful sensations produced by the faradic current consist of two elements, viz., cutaneous and muscular. The pain caused by muscular contraction when produced by a strong faradic current is considerable, and it has been noticed that patients in whom faradic muscular contractility is lost (p. 148) can stand stronger currents than those in whom it is not. The stimulating effect on sensory nerves (hence the production of pain) is greater from the secondary coil, with a moderate amount of interruption (500 per minute) and a high resistance (dry and small electrodes and a dry skin, p. 107). This is still further intensified if the coil is composed of fine wire and a great number of winds. From such a coil, if very rapid interruptions are obtained, sedative effects upon sensory nerves may be produced, these being due to a temporary paralysis (see p. 123). For such the resistance should be low, hence large and moist electrodes should be used (p. 107).

The Sinusoidal Current.—The influence of this current upon sensory nerves is very similar to that of the faradic, excepting that the disagreeable sensations caused by slow alternations are not so great as those produced by the faradic and the anesthetic effect produced by very rapid alternations (14,000 to 16,000 per minute) is greater. According to Kellog,[1] nerves of special sense may also be stimulated by it, waves of light being seen if the electrodes are placed upon the head; a metallic taste may also be produced, and thumping sounds in the ears.

The Static Current.—Static sparks, if small and thin, cause stinging and prickling sensations, to which is added, if the spark is stronger, a sensation of shock or jar. Pain may also be relieved by the static spark through its contractile influence (p. 124), and power to remove congestion and inflammatory exudate which may be pressing upon nerves. The static induced and static wave currents relieve pain in the same way. The electric souffle, or breeze, which consists of a current of electrified gaseous molecules impinging upon the skin (p. 20), has a sedative action and may relieve pain. The brush discharge (p. 245), if the patient is connected with the negative pole, has an anesthetic and soothing effect. It also may relieve pain in inflammatory conditions

[1] International System of Electrotherapeutics, second edition, pp c and 152 et seq.

by its power to contract and dilate the bloodvessels, hence promoting phagocytosis and promoting absorption of exudates. The current from the positive side is most efficacious for this purpose.

Currents of High Frequency.—When the electrode is in close contact with the skin only a sensation of heat is produced by this current, the smaller the surface of the electrode the greater being the heat. The skin area to which the electrode is applied becomes lessened in sensibility, even, according to D'Arsonval, to the extent of complete anesthesia;[1] this, however, soon passes off, lasting but fifteen minutes at most, and may be followed by hyperesthesia. If the electrode is not in close contact with the skin so that sparks pass, stinging, prickling sensations are felt. Local pain may be relieved by them for the same reasons that the static current does (p. 128). As the static current has greater contractile influence, it is believed by many to be more efficacious for this purpose.

EFFECTS PRODUCED WHEN THE CURRENT IS PASSED THROUGH THE BRAIN OR CORD.

The exposed brain, particularly the cortical motor centres, can be stimulated by the faradic current and made to functionate (p. 179). This, under ordinary conditions, cannot be done through the skull with currents of a strength that can be borne. The faradic current apparently has no influence whatever; the galvanic current when interrupted very rapidly exerts an influence upon the brain, manifested by inhibition of various centres and excitation of others. Leduc first demonstrated the fact that the galvanic current could be passed through the unopened skull, and described the symptoms.[2] The most marked phenomenon is the inhibition of cerebral centres so that general anesthesia and loss of voluntary movement is caused, to which has been given the name "electric sleep." Consciousness, however, is preserved. Disagreeable symptoms may also be caused, such as cardiac and respiratory paralysis, convulsive movements, and spasticity. Surgical operations have been performed under its influence, usually, however, in dogs, it not yet being regarded as safe for man.[3] It is asserted also that a local anesthesia may be produced if instead of applying the electrodes to the head they are placed in different parts of the body and a mild current used. Tait and Russ (*loc. cit.*) conclude that according to the strength of current and position of the electrodes, the Leduc current produces the following conditions, which appear in the following order: (1) Analgesia, superficial or deep, or both. (2) Respiratory and cardiac inhibition; epilepsy. (3) Electrocution. To obtain these phenomena a galvanic or constant current is employed which is broken

[1] This observation has been questioned by most observers.
[2] Archiv. d'elect. Med., September 15, 1903.
[3] Tait and Russ, Journal American Medical Association, November 13, 1909, p. 1611.

by a wheel interrupter a great number of times, so that each shock lasts but $\frac{1}{1000}$ second, followed by a passive period of $\frac{9}{1000}$ second. Other experimenters have modified these frequencies. In other words, it is a high frequency current (about 6000 per minute) of low potential, as constrasted with the high frequency current commonly employed, which is of high potential. An apparatus for the production of this current is made by the Wapper Electric Controller Co. of New York, and also by Gaiffe, of Paris. The galvanic current employed with slow interruptions, an electrode being placed on each side of the head, may cause dizziness (p. 127), nausea, a feeling of fulness in the head, faintness, and syncope. Very strong alternating currents cause convulsions and capillary hemorrhages into the brain substance.

It is doubtful if a current of therapeutic strength has any action upon the unexposed cord. Some (Erb, Massey, Morton) believe that it can be influenced. Very strong alternating currents cause capillary hemorrhages and various histological changes in the cells and fibers.

EFFECTS UPON VASOMOTER, SECRETORY, AND SYMPATHETIC NERVES.

The influence of electric currents upon vasomotor nerves is doubtful. If the *galvanic current* is applied to the skin, contraction of the vessels and consequent pallor is first produced, to be followed by dilatation and redness. The initial pallor is greater at the kathode, while the redness is greater at the anode. Very strong currents, if long continued, will cause at the kathode contraction of the vessels and pallor, followed by a pale redness with the formation of wheals and thickening and infiltration of the skin and sometimes vesication; at the anode a dark scarlet redness will occur, with small elevations upon the skin, but without thickening of it. This current is therefore a stimulant of the vasodilators. The *faradic current,* unless very strong, has no influence; it then causes pallor and cutis anserina, which may be followed by redness. If the dry brush (p. 176) is used, the redness produced is marked. *Static sparks* (p. 227) first cause vasoconstriction and pallor, followed by vasodilatation, with consequent redness and local rise of temperature. These effects are more marked with the positive than with the negative pole. In conditions where the vasomotor system is disordered, as in exophthalmic goitre, marked wheals are produced, and figures may be produced upon the skin (dermographism). Burch[1] claims that the static bath (p. 257) with positive insulation causes a rise in blood pressure, while with negative insulation a fall is produced. De Kraft[2] states that brush discharges (p. 245) cause dilatation of the superficial capillaries.

There is some difference of opinion as to the influence of *high fre-*

[1] Journal of Advanced Therapeutics, April, 1906, p. 183.
[2] Ibid., August, 1909, p. 370.

quency currents upon vasomotor nerves. D'Arsonval claimed that there was first marked dilatation of the vessels and fall of blood pressure, soon followed by constriction and rise of pressure. The truth of this assertion has been disputed by many. Thus Carvalho found no change in the blood pressure after autocondensation, but when a strong current was applied directly to the skin there was a fall of pressure. Moutier found that blood pressure was lowered by autocondensation (the opposite of D'Arsonval's finding), but he caused elevation of pressure of 2 to 3 cm. by applying the effluve from an Oudin resonator along the spinal column, a finding which contradicts that of Carvalho. Oudin, however, confirms the observation of Moutier. It has also been confirmed by Doumer, Denoyés, Crooneg, and Leduc. It has been found that the elevation of pressure only occurs when the application is of brief duration; if long continued, there occurs dilatation of the vessels, hyperemia, and fall of pressure. Burch[1] has endeavored to explain these discrepancies by asserting that they depend upon the psychical state of the patient at the time of the observation, together with the normal diurnal variation of arterial pressure, the influence of alcohol and tobacco, and the employment of different apparatus. His own experiments, carefully made and avoiding the above sources of error, showed that direct applications of quiet discharges (both direct applications from the resonator, the patient sitting with his feet upon a metal plate attached to the upper terminal, and static applications with a vacuum electrode being used) produced little or no effect upon blood pressure. On the other hand, autocondensation from a small D'Arsonval solenoid (Fig. 74) caused a marked fall in fifteen out of twenty observations. This is contrary to D'Arsonval's observation. De Kraft[2] states that in normal individuals currents of moderate amperage cause no alteration either in pulse rate or tension, but that currents of very large amperage may produce a very decided (even alarming) fall. He also states that if the pressure is high for the age of the person, there will be a diminution, while if the patient is in a generally weakened condition there will be a rise in pressure and stronger, steadier pulse. Some observers, notably T. Cohn and Loewy, have gotten entirely negative results. The Morton wave current (p. 258) is said by Snow to lower arterial tension (p. 135). On the other hand, Burch[3] got an increase of tension excepting in cases of arterial sclerosis with renal insufficiency, when there was often a marked fall. He also states that while both high frequency and static currents affect blood pressure through their influence upon the vasomotor system, the latter is much more definite and positive in its action.

Secretory nerves may be stimulated with the galvanic current; thus, if such a current is passed transversely through the cheeks a considerable secretion of saliva results, probably due to direct stimulation of

[1] Journal of Advanced Therapeutics, January, 1905, p. 32 et seq.
[2] Ibid., September, 1909, p. 415.
[3] Journal of Advanced Therapeutics, January, 1905, p. 36.

the chorda tympani, although some believe it to be a reflex excitement from irritation of the gustatory nerves. The flow of gastric juice is also excited by direct galvanization of the stomach. Sweating may also be excited. This may be noticed upon the skin during applications of the current. It seems to be especially present when either the tibial or median nerves are stimulated. Sweating is frequently observed during the application of high frequency currents.

The cervical sympathetic is the only sympathetic nerve that is near enough to the surface to be stimulated in the living subject, and it is so surrounded by other nerves and vessels, viz., the brachial plexus, pneumogastric nerve, and carotid artery, as to make any phenomena observed of doubtful origin. It has been claimed that faradization of the nerve produces dilatation of the corresponding pupil, contraction of the vessels, and unilateral pallor and coldness, followed by increased warmth. In galvanization (the anode upon the manubrium, the kathode at the angle of the jaw, or the kathode at the angle of the jaw and the anode at the side of the last cervical vertebra) circulatory changes in the retina and corresponding half of the face and ear, changes in the pupil at first dilatation, sometimes followed by contraction, may be observed. (Erb).

GENERAL AND METABOLIC EFFECTS

Constant or Galvanic Current.—This current tends to initiate, stimulate, and establish cell metabolism. It does this by its polar and interpolar action and power of causing electrolysis and cataphoresis. The polar actions may be here summarized as follows:[1]

Kathode or negative:

1. Physiological—stimulating.

2. Physiochemical—accumulation of the positively charged ions of hydrogen, sodium, potassium, calcium, and ammonium. Formation of an alkaline caustic, *i. e.*, the hydrates of sodium, potassium, calcium, and ammonium. Production of a soft, retractile eschar.

Cataphoric: Accumulation of fluid and basic ions, with mild currents nutrition promoted; with strong currents denutritive or destructive effect.

Anaphoric: Ability to diffuse the electronegative ions of certain substances, as sulphur, chlorine, iodine, etc. (p. 114).

Antiseptic, moderately. First effect of current, ischemia; second, hyperemia; ultimate effect, equalization of circulatory conditions.

Anode or positive:

Physiological: sedative.

Physiochemical: accumulation of negatively charged ions of oxygen and chlorine. Formation of an acid caustic, *i. e.*, sulphuric, hydrochloric, nitric, and phosphoric acids.

[1] Cleaves, Journal of Advanced Therapeutics, December, 1908, p. 645.

Cataphoric: Loss of hydrogen and basic ions; loss of fluid; coagulation. Starvation of tissues. Production of a dry, hard, and non-retractile eschar. Diffusion of ions of oxidizable metal electrodes or of ionized solutions.

Antiseptic: First effect of current, ischemia; second, hyperemia, but much less marked than at negative pole.[1]

The interpolar effects are as follows:[2]

1. Electrolysis (p. 113).
2. Transference of fluids in bulk from the positive to the negative pole (cataphoresis).

No other form of current possesses all of these properties in the same degree as does the galvanic, and hence its very marked both general and local effects and varied therapeutic applications. Its great influence in modifying nutrition and promoting absorption was early recognized by Remak, who termed it the *catalytic action* of the current, or *catalysis.* He has summarized them as follows (quoted by Erb): Dilatation of the bloodvessels and lymphatics, causing more ready circulation of the blood and nutritive fluids, and increased absorption; increased power of inhibition of the tissues; increased osmotic processes and thus increase of volume (especially in the muscles); changes in the disassimilation and nutrition of the nerves on account of their stimulation or sedation; changes in the molecular arrangement of the tissues caused by electrolytic processes; finally, the consequences of the mechanical transport of fluids from one pole to the other.

The strength of current employed has considerable influence in determining the nature of this action, viz., strong continuous currents (25 milliamperes or more) of considerable density are injurious to living tissue and depresses its nutrition, while mild currents (5 to 8 milliamperes) stimulate and improve it (p. 113).

Faradic Current.—The faradic or induced current possesses neither appreciable electrolytic nor polar action; it does, however, influence general nutrition. S. Weir Mitchell[3] found that general faradization (p. 252) causes some elevation of temperature. Rockwell[4] found that its persistent use in neurasthenic individuals produced improvement in nutrition, as shown by increase in weight, improvement in the pulse, relief of insomnia and constipation, and improvement of the appetite and digestion. It can readily be seen how anything which causes exercise of the muscles in those who have probably been having very little should produce such effects. Rockwell claims that the combined galvanic and faradic currents have a greater general effect than either used singly. This may be done by means of a suitable switch (Fig. 93). By this same device both currents may be passed through the patient at the same time (p. 123).

[1] In this summary it will be noted that local effects are given as well as general.

[2] W. J. Herdman, Action of Continuous Current within the Living Tissues as Distinguished from the Local Polar Action, Trans. American Electrotherapeutic Association, 1893, p. 68.

[3] Fat and Blood, p. 86.

[4] Medical and Surgical Electricity, p. 327 et seq.

Sinusoidal Current.—D'Arsonval has shown that when the entire body is submitted to the action of this current there is a general increase of the nutritive exchanges. This is shown by an increased absorption of oxygen by the blood and increased elimination of carbonic dioxide. The circulation is accelerated and the quantity of urea in the urine is increased. These changes are more marked when the alternations are very frequent.

Kellog,[1] who used this form of current as early as 1883, has experimented with a rapidly alternating sinusoidal induced current. The current is obtained by energizing the primary coil with a rapidly alternating sinusoidal or continuous current (17,000 per minute). He claims that this current is a powerful stimulant to the metabolic processes of the body; that muscular strength is increased, while the sensibility of the skin is diminished.

Static Electricity.—This, when administered as the electrostatic bath (p. 257), according to a number of observers, influences the body as follows: An increased frequency of the pulse, which may persist for some time after the treatment. A slight rise of temperature. An increase in respiratory combustion, which Bordier claims is due to the formation of ozone, which is more readily taken up by the blood cells than atmospheric oxygen. An increased excretion of urea. It has been claimed that if the seances are too frequently repeated the opposite will result. This, according to Truchot,[2] is due to incomplete oxidization, resulting from the organism burning too fast and hence burning badly. A diminution in the urinary phosphates and uric acid has also been noted and a decrease of the ratio of the total carbon in the urine to the carbon present in the albuminoids, corresponding to a diminution in the average weight of the molecule (Matre and Florence).

A tendency to sleep and increase in the digestive functions may also be produced.

The effects upon the circulation will be found on p. 130.

De Kraft[3] states that brush discharges (p. 245) applied along the spine and over the abdomen cause increased peristalsis, increased perspiration, drowsiness, and quotes McParlan as stating that when used after the static bath with positive insulation a marked increase in the red blood corpuscles takes place. He also states that it allays nervous irritability. The Morton wave current, which is really a current of high frequency, has been especially studied by Snow,[4] who divides its physiological action into constitutional effects and those due to the intense vibratory and peculiar electrical effects upon the tissues immediately beneath the electrodes, *i. e.*, the local effects.

[1] An International System of Electrotherapeutics, second edition, p. c, 157. Edited by Massey.

[2] Quoted by Guilleminot, p. 276.

[3] Journal of Advanced Therapeutics, August, 1909, p. 370.

[4] Transactions American Electrotherapeutic Association, 1900, p. 276.

"The constitutional effects are:

"1. Marked lowering of arterial tension.

"2. Lessened frequency of heart's action, with increased volume of pulse.

"3. Increased oxidation and metabolic activity, marked by body warmth, deepened inspiration, increased production of CO_2, increased elimination of solids, with marked functional activity of the organs of secretion and excretion.

"4. Marked diminution of nervous irritability, with sense of drowsiness.

"5. Sense of fatigue if sittings are too prolonged.

"6. Patients receiving local treatment for from forty-five minutes to two hours daily for periods of months, gain body weight, become less anemic, and improve generally in health."

The local effects depend on several causes (p. 134). They are:

"1. A sense of vibration, marked over muscles when there is little underlying fat by rhythmical contractions.

"2. Physiological tetanus is produced when voltage and alternations relative to muscle are applied.

"3. Sedation of pain and nervous irritability is produced by prolonged and gradually increased dosage as toleration permits.

"4. It is an antispasmodic, muscular spasm, being often overcome by prolonged administration of sufficient voltage to fatigue the muscle.

"5. Glands beneath the electrode are stimulated to active secretion.

"6. Local congestion and hyperemia when not due to specific poison or necrosis are relieved.

"7. Metabolism is most active beneath the electrode."

Burch (p. 131) differs from the above observations as regards the influence upon blood pressure.

High Frequency Currents.—By these we mean Tesla, D'Arsonval, and resonator currents (p. 98). In general it may be stated that the general effects of these are similar to those produced by static electricity (p. 134), only possibly in a greater degree. Burch,[1] basing his opinion on a number of experiments, says that high frequency currents stepped up from the secondary of a coil possess much more penetrative power, more actinic properties, and greater germicidal effects (p. 137) than those derived from a static machine. Also, that a high frequency apparatus activated by a static machine has greater penetration, actinic and germicidal properties than the current from the machine itself.

The subject is in a more or less experimental stage, and some (T. Cohn and A. Loewy, among others)[2] have denied that they cause such results. The bulk of opinion is that they do. The type of current used is also stated by some observers to give somewhat different results; thus, currents of comparatively *low voltage* and consequent low potential and *high amperage*, as those of D'Arsonval, and from the primary

[1] Journal of Advanced Therapeutics, December, 1904, p. 701.

[2] Berlin. klin. Woeh., 1900, p. 34.

Tesla coil, have a marked stimulative influence upon metabolism and elimination, while those of *very high potential* and *relatively low amperage*, as those from the Oudin resonator, Tesla secondary coil, or Piffard "Hyperstatic" Transformer,[1] produce less effects upon the chemical processes of the cells or metabolism, but are more stimulating to the nerves of the vasomotor and sympathetic systems, and exert a peculiarly characteristic action on vital resistance and trophic influence (Strong). It is possible that in time experience will show that different frequencies will also cause somewhat different results. Freund[2] claims that the essential element of these various modalities is potential. In other words, the greater the amount of current that can be borne, the greater the physiological action. His experiments also show that a larger amperage is also essential and that sparks are more active than quiet discharges. Furthermore, the action of the spark is intensified in proportion to its length and fatness. The static wave current produces more marked muscular contractions than the other modalities mentioned.[3] The static induced current discovered by Morton in 1881 (p. 231), which is the original form of high frequency current, causes marked muscular contraction and does so no matter how high the frequency. The reasons why currents of such enormous strength (600 to 800 milliamperes, for example) do not cause pain, excessive muscular contraction, and even death, are not positively known; it is known that if a current is interrupted 10,000 or more times per second, muscular contractions cease. Two hypotheses have been suggested: (1) Whether these currents, on account of their enormous frequency, pass exclusively upon the surface of the body, it being well known that currents of ordinary strength but of great frequency do not penetrate, but flow upon the surface of the conductor, as does static electricity. This view has been advocated by Tesla and others, who believed that the therapeutic effects produced were caused by reflex vasomotor excitation. Experiments have been performed by Margliano and D'Arsonval that seem to show that while true for metallic conductors, for the human body this view is incorrect, and that the currents do penetrate the body to some extent at least.[4] Freund,[5] however, states that the efficiency is due to the action of spark discharges on the skin. (2) Whether the sensory and motor nerves are organized to respond only to vibrations of determined frequency, as, for example, the optic nerve, the terminations of which are blind to undulations of the ether at a rate less than 497,000,000,000 (red) and greater than 728,000,000,000 a second (violet). The acoustic nerve also is deaf either above or below a certain number of vibrations per second. Another possibility is that these currents exercise upon nerve centres and muscles a marked inhibitory power. That some inhibitory power is possessed would

[1] Medical Record, October 20, 1900, and New York Medical Journal, June 16, 1906, p. 1218.

[2] Quoted by Burch. Journal of Advanced Therapeutics, December, 1904, p. 703.

[3] Of course, the lower the frequency the greater the contraction, and *vice versa*.

[4] Journal of Advanced Therapeutics, April, 1909, p. 183.

[5] Radiotherapy, p. 165.

seem to be shown by the more or less anesthesia produced by the current (p. 129).

BACTERICIDAL ACTION

Electricity, excepting with very strong currents, has but little bactericidal value. No way as yet has been devised to employ currents of sufficient strength in the human organism without doing injury to the structures of the body and causing great pain. The galvanic current has some action, particularly at the anode, this being due to the evolution of oxygen. The results of a number of experiments by Apostoli and Laguerriere[1] led them to the following conclusions:

1. In a homogeneous medium a constant galvanic current has no peculiar action *sui generis* upon cultivations of bacteria.
2. Whatever action it seems to have is due either to heating or chemical effects.
3. If the heating effects be prevented, or the electrodes be at some distance apart, then the only position at which any definite action can be observed is at the anode.
4. Under these conditions no action seems to occur either at the kathode or in the rest of the circuit.
5. This anodal action is purely chemical or electrolytic, and is especially connected with the nascent oxygen liberated, for if this be absorbed all bactericidal action is lost.
6. The action increases with the current strength (after a minimum of 50 milliamperes has been passed) and with the duration of the application.
7. A current of a strength below 50 milliamperes can restore virulence to an attenuated culture, and thus act as a revivifying agent.

Freund[2] quotes a number of experiments which show that spark discharges from the secondary of a Ruhmkorff coil (p. 94), especially the negative pole, and also the high frequency discharges from a D'Arsonval-Oudin apparatus (p. 101), exercised an inhibitory effect upon the growth of bacteria and destroyed them when grown. All forms of pathogenic bacteria were so destroyed, but the methods used were not applicable to the living human subject. F. Robert Zeit[3] has investigated this subject thoroughly, and his conclusions as to its practical value were negative.

High frequency and static discharges may exercise some slight antiseptic effect by the formation of ozone, which is produced by such discharges. They also may be of value by causing a local hyperemia and consequent local leukocytosis. The brush discharge (p. 245) has been recommended, DeKraft claiming that boils may be aborted.[4]

Recently, however, Clark and B. A. Thomas have obtained positive results by a new method (p. 270).

[1] Revue d'Electrothérapie, August, 1891. Also quoted by Freund in Radiotherapy, p. 140.

[2] Radiotherapy, p. 126 et seq.

[3] Effect of Direct, Alternating, Tesla Currents and X-rays upon Baeteria, Jour. Amer. Med Assoc. 1901, xxxvii, 1432.

[4] Journal of Advanced Therapeutics, August, 1909, p. 372.

CHAPTER VII

SUMMARY OF THE PHYSIOLOGICAL ACTION OF THE VARIOUS ELECTRIC MODALITIES

A SUMMARY of the various effects of the current which have been detailed in the preceding chapters may prove of service.

GALVANIC OR CONSTANT CURRENT

This is the only current that possesses all physiological effects in a marked degree. It is the only one that has marked polar action, although this may be present in some degree in both faradic and static electricity. If not suddenly interrupted, muscular contractions are not caused by it; if this is done, contractions occurring according to a constant formula (p. 120) are produced. It also causes contraction of involuntary muscles. The positive pole is sedative to both motor and sensory nerves; the negative is stimulating (p. 115). A more or less electrolytic disintegration of the tissues through which the current passes occurs, being greatest at the poles, a general interchange takes place, oxygen and the elements or acid radicals moving from the negative to the positive pole, while the hydrogen, metals, metallic radicals of the salts and bases go from the positive to the negative pole (p. 113).

By the cataphoric action fluids are driven from the positive toward the negative pole. By this desiccating effect of the anode congestion is lessened and hemorrhage checked, while congestion takes place at the negative pole, which may be of service in impaired nutrition or when it is desired to draw blood to a part. The electrolytic and cataphoric phenomena also quicken cellular metabolism, promote absorption, and remove exudation—especially the negative pole (p. 132). By the formation of oxygen some antiseptic effect may be produced by the positive pole. The electrolytic properties of the negative pole, when a relatively strong current is employed, may be used to destroy abnormal growths and tissue, while that of the positive pole may be employed to coagulate blood (p. 113). By its anaphoric and cataphoric action drugs may be introduced into the body through the skin (p. 114). It is also of assistance in diagnosis (see Section III).

FARADIC OR INDUCED CURRENT

This produces muscular contractions, excepting in some forms of paralysis (p. 147), and hence is of assistance in diagnosis (see Section III).

Under certain conditions it stimulates sensory nerves, under others it may act as a sedative both to sensory and motor nerves (pp. 121 and 128. By means of its power to exercise muscles and irritate the skin (p. 128) it probably has some influence in improving general nutrition (p. 133).

SINUSOIDAL CURRENT

This produces muscular contractions without causing the disagreeable sensations caused by the faradic, and also exercises a marked contractile influence upon involuntary muscle. If the alternations are very rapid, it may exercise a sedative effect upon painful nerves. General nutrition and metabolism are also said to be improved by its use.

STATIC CURRENT

Sparks cause muscular and tissue contraction by which, when local stasis or congestion is present, the fluid contents of the tissues are forced in the direction of the various outlets, both vascular and lymphatic; pain is thus relieved and exudation removed (Burch). The positive spark is less painful than the negative. Brush discharges (p. 245) cause dilatation of the capillaries, thus producing a local leukocytosis, restores the stagnant circulation to a normal basis, thus softens hardened tissues and relieves pressure and pain (see also p. 124). It is also claimed to increase the number of red blood corpuscles and hemoglobin (p. 134). If strong, a destructive action upon skin is exerted by the spark, which may be utilized to destroy growths (p. 268). The spray or breeze (p. 243), especially if positive with negative insulation, is soothing and relieves pain; when employed in the opposite manner it is more irritating. The static bath, positive insulation (p. 130), probably causes a rise of blood pressure which, with negative insulation is lowered. A general increase in metabolism is also produced. The static wave current of Morton has marked contractile power, increases metabolism, and relieves local congestion and pain (p. 135). The static induced current has a similar action, but not so marked. It will be seen that static electricity has polar action, the negative being stimulating and the positive sedative. Hence in employing it this point should be carefully studied. It also has a marked psychic effect.

HIGH FREQUENCY CURRENTS.

Sparks from a vacuum glass electrode (p. 238) exert a similar influence to the static spark and brush discharges (pp. 124 and 128), hence in a similar way they may relieve pain and promote the absorption of inflammatory exudates. The sensibility of the skin may be lessened. They also appear to influence blood pressure and metabolism (pp. 131

and 135). Solutions may be caused by them to penetrate the skin (p. 277). A destructive effect similar to that of the static spark is also caused. The physiological effects of vacuum tube discharges have been summarized by Burch[1] to be due to: (1) The more refrangible light frequencies emanating from the fluorescing tube itself (blue, violet, ultraviolet). (2) The chemical effects of nascent ozone. (3) The effects of ionization. (4) Heat. (5) Mechanical vibratory effects. (6) Germicidal effects. (7) The effects of the electrostatic discharge itself.

The germicidal effects are probably due to the ozone produced. Similar views to the above are held by Freund.[2] He also mentions an important effect, *i. e.*, that spark discharges of whatever origin may induce changes in the skin. When the discharges are weak and only operative for a short time, merely superficial inflammation and small-celled infiltration were noticed in the upper layers of the cutis, but when powerful and long-continued sparks are used, marked alterations are produced in the tissues, consisting of small-celled infiltration of the deeper layers of the epidermis, extensive extravasation of blood and vacuolization in the intima of the arterioles (changes similar to those produced by Röntgen rays). When applied to surfaces covered by hair, the hair is thinned out, bald spots appearing in places.[3] While high potential discharges, viz., from Ruhmkorff coil, or strong alternating currents or lightning stroke, such effects are not only produced at the site of application, but in distant organs (p. 130); those of great high frequency and tension only produce the effects at the site of application, distant localities not being visibly affected. Freund, after many observations, was unable to decide if these changes were due to the mechanical action of the spark or the electricity itself. He inclines to the latter view. The lessened sensibility of the skin, he thinks, can be attributed, in part at least, to "mechanical concussion" or the mechanical action of rapid bombardment of the tissues. He also is of the opinion that important factors in producing general therapeutic effects are this local irritation of the skin and nerve terminals which reflexly influences distant organs,[4] shocks produced by the current interruptions, and the effects of electric vibrations. Such effects may not only be caused by high frequency sparks, but by those from the static machine and with strong faradic or induced currents applied with a dry brush electrode, and that any difference which may exist depends merely upon the strength of current employed. Quiet discharges, either autoconduction or condensation (p. 262), produce changes in blood pressure, influence metabolism, and stimulate nutrition (p. 135), possibly by influencing

[1] Journal of Advanced Therapeutics, April, 1909, p. 184.

[2] Radiotherapy, p. 161 et seq.

[3] Loc. cit., pp. 146 to 155; also Journal of Advanced Therapeutics, January, 1905, p. 29.

[4] The observations of Head (Brain, 1893 and 1894) showing the relation of peripheral nerves to internal organs are of particular interest in this connection. He showed that diseases of the viscera caused areas of pain and tenderness in skin areas, there being a constant relationship between the organ affected and the tender and painful area.

vasomotor nerves (Freund) or directly affecting the protoplasm (D'Arsonval).

Later observations[1] endorse these conclusions. Bailey summarizes them as follows: (1) Increased cell activity, increased metabolism; (2) return of a locally inflamed tissue to its normal; (3) either general vascular dilatation or contraction according to the particular method used; and (4) "inhibition," diminished motor or sensory excitability. So that where one or more of those effects are desired and where the remaining effects are not prejudicial, or can be very much diminished or abolished, then high frequency treatment may be of real value.

[1] Bailey, Lancet, July 3, 1909.

SECTION III

ELECTRODIAGNOSIS AND ELECTRO-PROGNOSIS

CHAPTER VIII

DISORDERS OF THE MOTOR TRACT AND MUSCLES

GENERAL CONSIDERATIONS

The electric current is of aid in the diagnosis of certain pathological conditions. This is especially true of disorders of the motor tract and muscles. It also, when the existence of certain of these conditions is determined, is of some assistance in making a prognosis. To appreciate the nature of the changes to be looked for in employing the current for purposes of diagnosis it is essential to bear in mind the manner of contraction of the healthy muscle. This has been discussed on page 110.

The important points to remember are: First, when one electrode of a faradic battery is placed over either a normal muscle or its supplying nerve (p. 161), and the other at some indifferent point, if the current is of sufficient strength, there will occur a contraction of that muscle. Second, if the galvanic current is employed instead of the faradic, the electrodes being similarly placed, and the current gradually increased in strength, the first response will occur when the circuit is closed at the kathode or, in other words, when the circuit is closed while the kathode is over the muscle or nerve. And as the current is increased anodal closure, then anodal opening and finally kathodal closure contractions will appear. This last, however, is rarely seen, as very strong and hence painful currents are required to produce it. Third, that these contractions are quick and sharp. Fourth, that about the same strength of current (either faradic or galvanic) will cause an equal amount of response in the corresponding muscles of each side.

The variations that may occur in pathological conditions and which are to be looked for are: (1) If there is increased excitability, meaning by this that a weaker current causes contraction that would be required for the corresponding muscles of the normal individual; if there is

diminished excitability, meaning that a stronger current is required to produce a contraction than is required by the normal muscle. These, when present, are known as *quantitative changes,* the former being sometimes termed *quantitative increase* and the latter *quantitative decrease.* (2) The character of the contraction, whether it is quick and sharp, as is normally the case, or either slow, wave-like, and tetanic, or easily exhausted. When the galvanic current is employed, whether the contractions occur in the normal sequence or not, *i. e.,* any deviations from the formula KClC, AnClC, AnOc, KOC. These are known as *qualitative changes,* the alteration in the character of the contraction being sometimes designated by the term *modal change* and the variation in the sequence as *serial change* or "reversal of the law of contraction." Quantitative and qualitative changes may occur either separately or combined.

SIGNIFICANCE OF QUANTITATIVE CHANGES

Increased Excitability.—With the exception of the galvanic response of the muscles during the early stages of the reaction of degeneration, in myotonia congenita, in which the so-called myotonic reaction (p. 156) is present, in tetanus and tetany, *increased excitability* is of rare occurrence. While the use of electricity would hardly be required to assist in the diagnosis of tetanus, in tetany it is of much service. In this disease the increased excitability of the motor nerves is marked, and characteristic when the galvanic current is employed. A very weak current (1 milliampere or less) giving KClC, a slight increase will cause a tetanic contraction (KClTe). AnClTe and AnOTe, which never occur normally, may be caused by mild currents, and frequently KOC has been obtained with currents of 5 milliamperes or less. And rarely KClTe has been observed. As has been previously said (p. 110), KOC cannot be elicited in a normal muscle.

This pure increase of excitability is practically pathognomonic of tetany. It is known as Erb's phenomenon, also Hoffman's. It does not occur in muscular spasm due to any other cause. The ulnar nerves are especially excitable.

H. M. Thomas[1] found in one case a phenomenon which he termed *katelectrotonus tetanus.* That is, when the kathode was placed on the nerve, and the current was exceedingly weak—so weak, in fact, that the meter did not indicate the passage of any current—fibrillary contractions were noticed in the muscles, and as the current was increased the contractions became more marked and the muscles became tetanized, which continued to increase until all the muscles supplied by the nerve were thrown into a strong tonic spasm, which passed off suddenly if the current was suddenly broken, or gradually if it was gradually decreased.

[1] Johns Hopkins Hospital Bulletin, 1895, vol. vi.

This phenomenon did not occur if the anode was substituted for the kathode. It has been also observed once by von Bechterew, who has also lately called attention to the fact that repeated stimulation will cause a progressive increase in this excitability. He has called this *the reaction of excitation.* Increased excitability may be noticed with the faradic current, but is not so constant.

Quantitative increase may rarely be detected in cases where there is an irritative condition of the nerve centres or tracts, as in recent hemiplegia, the early stages of brain tumors, neuritis, and myelitis.

Diminished Excitability.—This change is usually found where there has been a slight lesion of the peripheral neuron (p. 147), as in very mild cases of neuritis; in cases that have been more severe, but have greatly improved, and in the early stages of progressive muscular atrophy. In the latter affection the diminution may only be noticed when strong currents, that produce marked contractions in the healthy muscle are employed, the weakest current that will cause a contraction (minimal contraction) being the same in both healthy and diseased muscles. That merely a quantitative change should be present in such cases will be understood when it is remembered that many of the mild cases of neuritis, those due to rheumatism especially, consist of merely an inflammation of the connective tissue of the nerve trunk (perineurium, endoneurium, neurilemma), and that pressure upon the nerve fibers due to the consequent increase of connective tissue causes the interference with their functions; of course, in more severe cases or even later, sometimes in the mild ones, the nerve fibers become secondarily affected and degenerated, and the reaction of degeneration occurs (p. 147). In progressive muscular atrophy the motor cells in the anterior horns of the cord degenerate gradually and a few at a time, hence the fibers of the affected muscles will also degenerate in the same way, and consequently each muscle will until late in the disease contain a more or less number of healthy fibers which will contract normally. Later the reaction of degeneration may occur. In that form of atrophy which occurs in the muscles about inflamed joints, known as arthritic atrophy, and which is probably due to some disturbance of the peripheral neuron, either a normal response or a quantitative decrease may be present. While diminished excitability usually denotes disease of the peripheral neuron as above indicated, it may also be present in disease of the muscle, as in the progressive muscular dystrophies or myopathies, inflammation of the muscles, or myositis, and in muscles which have been disused for a long time, either from being in splints or bandages (Volkman's contracture), and in functional paralysis due to hysteria. When such change does occur in an hysterical paralysis, it is of much diagnostic importance in differentiating it from simulation, and hence may, if the hysteria is due to a traumatism (traumatic neurosis), be of some medico-legal importance. It must be borne in mind, however, that a normal response does not prove that the case is not genuine. More rarely it may be encountered in disease of the central neuron, especially when

10

of long standing and the muscles have been little used, as in old cases of paralysis following either apoplexy or chronic myelitis, also when there are marked contractures.

SIGNIFICANCE OF QUALITATIVE CHANGES

The only pure qualitative change of practical importance is the *myasthenic reaction.* Another of no practical value is the *neurotonic reaction.*

Myasthenic Reaction.—This is only found in the disease known either as myasthenia gravis pseudoparalytica or asthenic bulbar palsy. It shows itself by a rapid exhaustion of the power of the muscle to contract when stimulated by the faradic current. Thus, when first stimulated the muscle contracts normally, but with each successive stimulation the contraction becomes shorter and weaker until finally it does not respond at all. After a short rest the muscle will again contract when stimulated, to again become exhausted if the stimulation is continued. In testing for this reaction it should be remembered that it is dangerous to test the muscles of the chest, as there have been cases in which dangerous failure of respiration has occurred from their exhaustion. A small electrode should be placed over the nerves and the motor points of the muscles (p. 162) and the rapidly interrupted current used. The muscles of the face cannot be tested with satisfaction, owing to the pain produced. The muscles should be made to contract for at least five minutes.

Mosher, during the electrical examination of a case of myasthenia gravis, reported by Hun in the *Albany Medical Annals* for January, 1904, found that in addition to the exhaustion of the muscle, as above described, this exhaustion was frequently manifested by intermittent, jerky contractions, with the muscle partly, but not completely, relaxed in the intervals. Thus, in examining the biceps, "there was first a tetanic contraction, lasting fifteen seconds, followed by intermitting, jerky contractions, with the muscle partly but not completely relaxed in the intervals, the intervals becoming noticeably longer after two minutes, but the contractions not less powerful until after three minutes, when both the interval became longer and the jerky contraction less powerful. During the fifth minute there were fifteen of the jerky contractions, ten in the first half and five in the second." He also noticed that there was slight diminution of galvanic excitability, a stronger current being required to excite the nerves and muscles than was required for a normal person, but exhaustion was not caused as by the faradic. The rapidity of exhaustion depends upon the degree of myasthenia in the affected muscle. It may also differ from time to time and may be present in the muscles supplied by one branch of a nerve and absent in other muscles supplied by the same nerve (Goldflam).

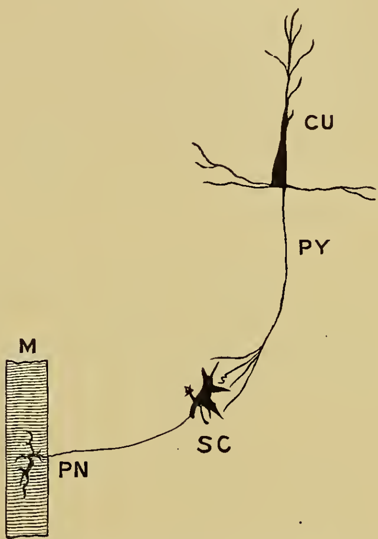
Neurotonic Reaction.—This consists in a tonic persistence of contraction after stimulation has ceased, similar to that seen in the myotonic

reaction (p. 156), but differs from it in that it occurs only when the nerve is stimulated and with either the galvanic or faradic currents. Another feature of it is the early appearance of AnOC and KClTe. It is of rare occurrence and its significance is not known.

QUANTITATIVE AND QUALITATIVE CHANGES

The greatest value of electricity in diagnosis is in determining whether the seat of the lesion causing motor paralysis is either in the central or peripheral neurons. By the central neurons, meaning the cortical nerve cells and their axons, which constitute the pyramidal tracts, and by the peripheral, the cells in the anterior horns of the cord and nuclei of the motor cranial nerves and their axons, which constitute the peripheral nerves (Fig. 94). When the lesion is in the central neuron the muscles affected and their supplying nerve usually respond to both the faradic and galvanic currents, as do the normal muscles and nerves; this is also true in many cases where the muscles alone are affected.[1]

Fig. 94



CU represents a cell in the motor region of the brain cortex; *PY* is its axon, which forms part of the pyramidal tract; *SC* represents a cell in the gray matter of the cord (anterior horns); *PN*, its axon, forming part of a peripheral nerve; *M*, muscle. A lesion destroying *CU* or any part of the tract *PY* causes a central palsy; a lesion destroying *SC* or any part of the tract *PN*, a peripheral palsy.

If, however, the seat of the lesion is in the peripheral neuron, there is usually[2] a greater or less change from the normal response, which may consist of either a quantitative change, consisting of diminished excitability (p. 145), or a combined quantitative and qualitative change, termed by Erb "*the reaction of degeneration*," usually designated by the symbols either DeR, RD, or DR. Another quantitative and qualitative change of value in diagnosis is the *myotonic reaction* (p. 156); one of much less importance is the *myoclonic contraction* (p. 157).

REACTION OF DEGENERATION

By this, as defined by Erb, we mean "an entire cycle of quantitative-qualitative changes of irritability, which occurs in the nerves and muscles under certain pathological conditions, and presents intimate relations

[1] For exceptions to this see pages 145 and 146.

[2] Palsies due to pressure, while caused by a peripheral lesion, usually respond normally.

to certain histological degenerative changes occurring in these structures. It is characterized, in the main, by diminution and loss of the faradic and galvanic irritability of the nerves, and the faradic irritability of the muscles; while the galvanic irritability of the muscles persists, is sometimes considerably increased, and is always changed qualitatively in a definite manner." This definition applies to the completely developed reaction which is not always found, it being more or less complete, according to the amount of degeneration of the nerve and the rapidity of its development. Hence it occurs in *complete* and *incomplete* forms, the latter being usually termed "*a partial reaction of degeneration.*"

The mode of development of the complete DeR is as follows: After the development of the lesion, the affected nerve may, for one or two days, in very rare instances, show an increase of excitability. The rule is, however, that the nerve shows a progressive diminution of irritability to both the faradic and galvanic currents,[1] which begins either immediatly or within the first few days. By the end of the first or second week faradic and galvanic excitability of the nerve have completely disappeared. According to Erb, this diminution begins in that portion of the nerve nearest the lesion, but it is obvious that in all cases this point either cannot be ascertained, or else is not accessible to stimulation, as in cases of acute poliomyelitis, for instance. The reaction of the muscles when they are stimulated differs from that of the nerves, those being a distinct difference in their behavior to the faradic and galvanic currents. When the former is used there is a diminution of excitability progressing to extinction, similar to that which occurs in the nerves. When the latter is employed, there may, during the first week, be some diminution of excitability which is succeeded by a marked increase, which continues and may increase during a period ranging from three to eight weeks. After a variable length of time the most excitable point of the muscle may also change its position. Instead of being at the motor point (p. 162), it is at the distal end of the muscle, *i. e.*, where the fibers join the tendon. This phenomenon has been termed by Doumer "the longitudinal reaction."

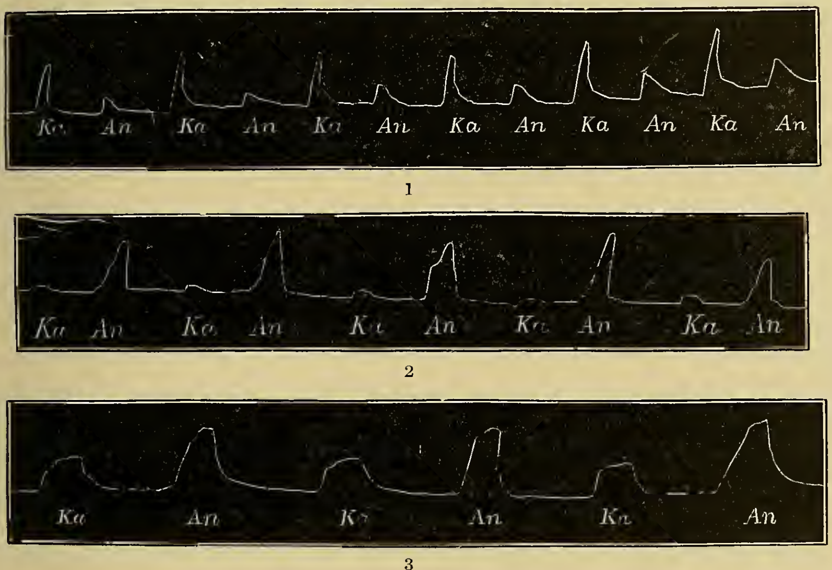
Coincident with this increased excitability occur changes in the mode of contraction. These are as follows: Instead of the short, lightning-like contraction of the normal muscle, the contraction becomes more or less slow, long drawn out, and tetanic in character, sometimes termed the *modal change*.[2] At the same time, AnClC increases and finally becomes either equal to or greater than KClC, so that it occurs either with a weaker current than is required to produce KClC or with one

[1] In a case of facial paralysis due to disease of the seventh nerve (Bell's palsy) seen by the author, increased excitability of the nerve persisted for several weeks. In another very mild case there was an increased response to the faradic current.

[2] While not usually the case, sometimes when partial DeR is present this slow contraction may occur when the nerve is stimulated. It may also occur under similar circumstances when the muscles are stimulated by the faradic current.

of equal strength. This phenomenon is usually indicated as follows: AnClC = KClC when equal, or AnClC > KClC when greater. At the same time also KOC increases, so that it may become equal to or greater than AnOC; the latter, however, is exceedingly rare. Instead then of the normal formula KClC″, AnClC′, AnOC, KOC we have AnClC = KClC, or AnClC > KClC, and KOC = AnOc, or KOC > AnOC. In other words, the normal formula is reversed. This change is often termed the *serial change*. These changes (modal and serial) are indicated in the diagrams constituting Fig. 95. If the condition improves in a greater or less period of time (from a few weeks to months),

Fig. 95



Curves of closure contractions in direct (unipolar) stimulation of the muscles in the distribution of the peroneal of the leg; Ka = KaClC.; An = AnClC. 1. Curve in a healthy girl, 33 elements; KaClC considerably greater than AnClC. 2. Case of chronic anterior poliomyelitis, DeR curve in the peroneal distribution, 33 elements; AnClC much greater than KaClC. 3. The same case with 40 elements; predominance of AnClC and slow character of the contractions very marked. (Erb.)

according to the severity of the lesion, faradic and galvanic irritability gradually reappear in the nerve and faradic irritability in the muscles. It should be noted that the former change may not occur for some time after voluntary contraction has returned. After a period of from three to eight weeks the increased galvanic excitability of the muscles disappears and gradual diminution of excitability occurs, in extreme cases KClC gradually disappears and finally AnClC only can be obtained, the slow contraction, however, continues. Then the normal mode of contraction gradually returns, although this may not be manifest until some time after normal contractions may be obtained by stimulation of the nerves and voluntary motion is restored. In incurable cases the loss of

excitability of the nerve continues, and finally galvanic excitability of the muscles disappears, although it may be a long time (sometimes years) before this latter phenomenon occurs. Various degrees of the *partial* DeR occur. For instance, there may be a diminution only of faradic and galvanic excitability of the nerve and faradic excitability of the muscle, while the response of the muscles to the galvanic current is as above described, or there may be diminished excitability, as above mentioned—KClC > AnClC, and the occurrence of the slow contraction. In such cases, however, AnClC is usually relatively greater than would be found in a normal muscle, and there is for a time increased excitability. In large muscles which are supplied by several nerves, there may be a complete reaction in one part of the muscle and a partial in another. In the later stages of the reaction, if the degenerated nerve or cells regenerate while the atrophy of the muscles is still considerable, we may have a normal muscular response when the nerve is stimulated, and a reaction of degeneration when the muscles are directly stimulated.

Fig. 96

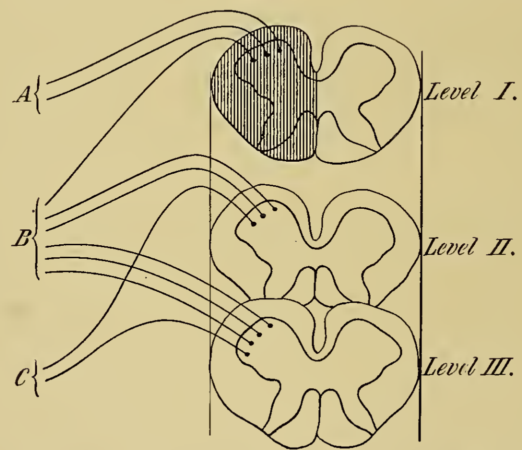


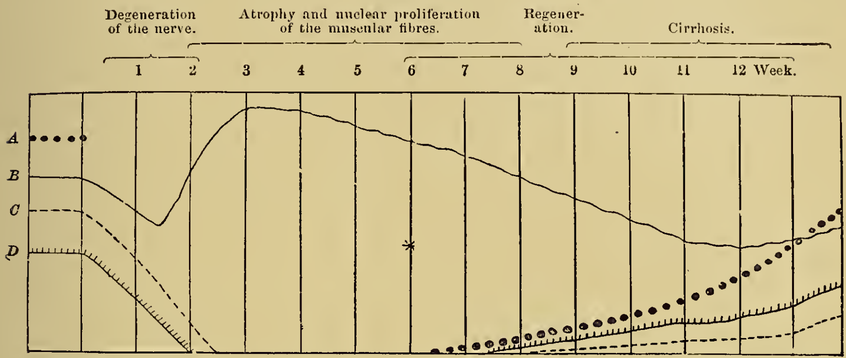
Diagram of spinal cord localization. *A*, *B*, *C*, to muscles. (Cohn.)

Also, under some conditions there may be different degrees of DeR in muscles supplied by the same nerve. This depends on the fact that the anterior horn cells from which each nerve arises will be found in at least three segments of the cord; hence if only one segment was diseased, the condition might be as in Fig. 96. Thus, in the muscles *A*, *B*, and *C*, muscle *A* would show complete DeR, *B* partial or diminished excitability, and *C* might react normally. The essential feature of the DeR is *the slow, long-drawn-out tetanic contraction produced by galvanic stimulation of the muscles* (modal change), as diminished faradic contractility may be due to other causes (p. 145), and the serial change may not occur.

The following diagrams from Erb will show the development of the various degrees of the DeR in Figs. 97, 98, 99, and 100.

E. Reiss[1] has recently described another phenomenon in degenerated muscle which he describes as follows: A healthy muscle contracts

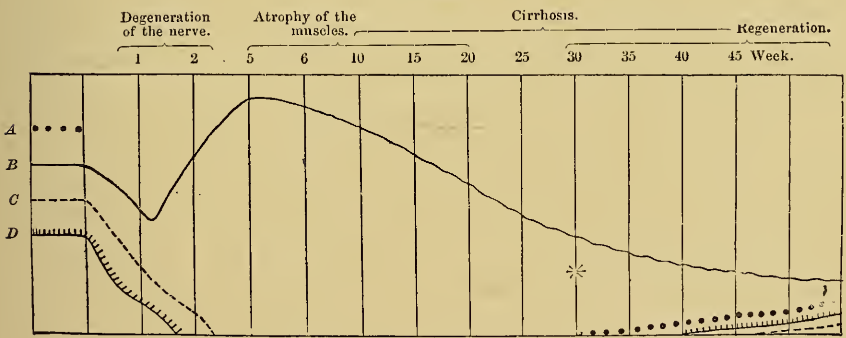
FIG. 97



Paralysis with relatively early return of motion. (Erb.) *A*, voluntary motion; *B*, galvanic excitability of muscle; *C*, faradic excitability of muscle; *D*, excitability of nerve to either current; *, return of voluntary motion.

sharply when the galvanic circuit is suddenly closed, whereas if the circuit is closed with a very weak current, and then gradually increased, no contraction will occur until the current is exceedingly strong (stronger than can be ordinarily stood by a conscious person). A degenerated

FIG. 98



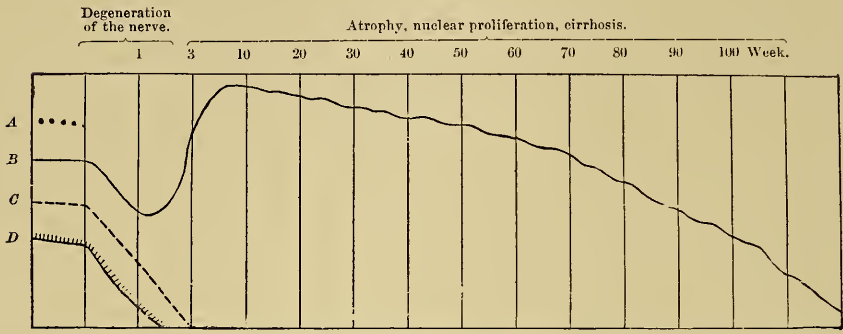
Paralysis with late return of motion. (Erb.) *A*, voluntary motion; *B*, galvanic excitability of muscle; *C*, faradic excitability of muscle; *D*, excitability of nerve to either current; *, return of voluntary motion.

muscle, however, will be found to react equally well to any given strength of current, whether the current is sent through by a sudden closure or by gradual increase. This is only markedly found in com-

[1] Verhandl. d. deut. Kong. für inn. Med., 1910, S, 536.

plete reactions. In the partial reaction the difference in strength of current required to elicit a minimal contraction by sudden closure and

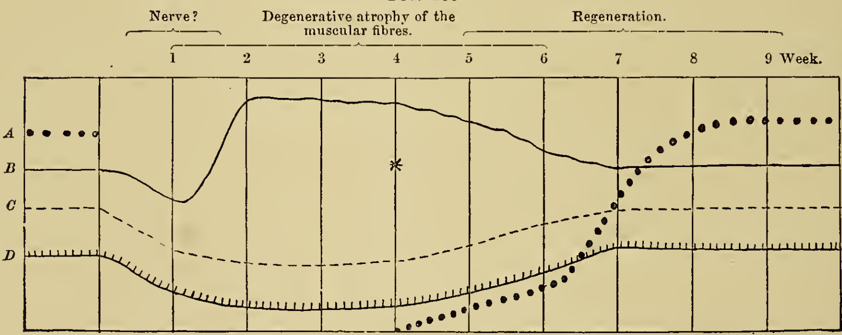
Fig. 99



Incurable paralysis. Motion lost permanently. (Erb.) *A*, voluntary motion; *B*, galvanic excitability of muscle; *C*, faradic excitability of muscle; *D*, excitability of nerve to either current.

by gradual increase will be found to be less in the case of the affected muscle than in the corresponding healthy one.

Fig. 100



Schematic representation of partial degenerative reaction. (Erb.) *A*, voluntary motion; *B*, galvanic excitability of muscle; *C*, faradic excitability of muscle; *D*, excitability of nerve to either current; *, return of voluntary motion. The faradic and galvanic irritability of the nerve and the faradic irritability of the muscle are diminished to a slight extent. Motor power returns at an early period; complete and rapid recovery. Degeneration of the nerve probably absent.

Significance of the Reaction of Degeneration.—As has already been said, the presence of any degree of the reaction of degeneration indicates a lesion somewhere in the peripheral neurons, hence either the cells in the anterior horns of the cord or nuclei of motor cranial nerves, or the peripheral nerves. The partial reactions are found in cases either where the lesion has not caused complete degeneration of the nerve or in cases which have been complete and regeneration is taking place. Hence in less severe cases of neuritis, especially the so-called rheumatic forms, in cases where the nerve trunk is pressed upon by tumors or

callus, in progressive muscular atrophy (p. 145), amyotrophic lateral sclerosis, progressive bulbar palsy, and in mild cases of acute poliomyelitis. The complete reaction indicates complete degeneration of the nerve, and is found in severe cases of neuritis after traumatism that divides or crushes the nerve, due to pressure on the nerve by a tumor or callus, in most cases of acute poliomyelitis, and in the later stages of progressive muscular atrophy, amyotrophic lateral sclerosis, and glossolabiolaryngeal paralysis (progressive bulbar palsy) (p. 157).

Relation of the Muscles to the Segments of the Spinal Cord

Segment.	Muscles.
Second and third cervical.	Sternomastoid. Trapezius. Scaleni and neck. Diaphragm.
Fourth cervical.	Diaphragm. Deltoid. Biceps. Coracobrachialis. Supinator longus. Rhomboid. Supra- and infraspinatus.
Fifth cervical.	Deltoid. Biceps. Coracobrachialis. Brachialis anticus. Supinator longus. Supinator brevis. Deep muscle of shoulder blade. Rhomboid. Teres minor. Pectoralis (clavicular part). Serratus magnus.
Sixth cervical.	Biceps. Brachialis anticus. Subscapular. Pectoralis (clavicular part). Serratus magnus. Triceps. Extensors of wrist and fingers. Pronators.
Seventh cervical	Triceps (long head). Extensors of wrists and fingers. Pronators of wrist. Flexors of wrist. Subscapular. Pectoralis (costal part). Serratus magnus. Latissimus dorsi. Teres major.
Eighth cervical.	Triceps (long head). Flexors of wrist and fingers. Intrinsic hand muscles.
First dorsal	Extensors of thumb. Intrinsic hand muscles. Thenar and hypothenar muscles
Second dorsal.	. . . .
Second to twelfth dorsal.	Muscles of back and abdomen. Erectores spinæ.
First lumbar.	Iliopsoas. Rectus. Sartorius.
Second lumbar.	Iliopsoas. Sartorius. Quadriceps femoris.
Third lumbar.	Quadriceps femoris. Anterior part of biceps. Inward rotators of thigh. Abductors of thigh.
Fourth lumbar.	Abductors of thigh. Adductors of thigh. Flexors of knee. Tibialis anticus. Peroneus longus.
Fifth lumbar.	Outward rotators of thigh. Flexors of knee. Flexors of ankle. Peronei. Extensors of toes.
First and second sacral.	Flexors of ankle. Long flexor of toes. Intrinsic foot muscles.
Third, fourth, and fifth sacral.	Gluteus maximus. Perineal. Muscles of bladder, rectum, and external genitals.
Fifth sacral and coccygeal.	Coccygeus muscles

In cases of either transverse myelitis, syringomyelia, tumor, and other focal lesions of the cord, the presence of the DeR may assist in the localization of the lesion; for in cases of transverse myelitis, syringomyelia, tumor, or hemorrhage, if the lesion is in a part of the cord which gives rise to nerves that supply muscles accessible to electrical examination, *i. e.*, the gray matter of the cervical and lumbar enlargements, the muscles affected will be found to give a more or less developed DeR, and as the relation of the different muscles to the segments of the cord is known with a fair degree of accuracy, the presence of the DeR in certain muscles would point to a lesion in the gray matter of the particular segments controlling them. These relations are shown in the table prepared by Starr (see p. 153); the sensory and reflex functions are omitted. The muscles supplied by the dorsal segments, excepting the abdominal, are not so eligible for accurate electrical examination, as they cannot be isolated.

Similar assistance may be obtained when the lesion, *i. e.*, tumor or limited area of meningitis, is extraspinal, but involves the anterior nerve roots as they immerge from the cord.

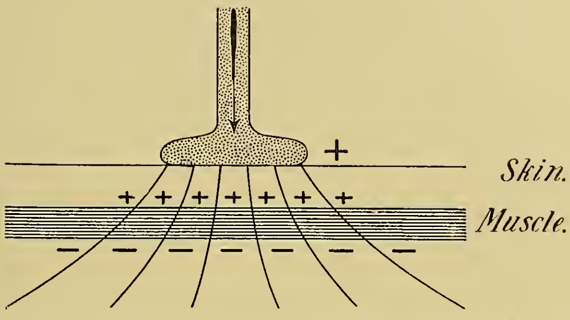
Explanation of Why DeR Occurs.—No very satisfactory explanation has ever been given for the occurrence of all the various changes in electric irritability and mode of contraction which go to make up the DeR. The disappearance of faradic and galvanic excitability of the nerve is due probably to the destruction of the nerve fibers and consequent inability for stimulation to reach the muscle. As the nerve fibers regenerate, excitability returns, increasing as the number of regenerated fibers increase. According to Erb, the excitability of the nerve first appears in its peripheral or distal portion. That electrical irritability does not return until after the power of conducting voluntary impulses has, seems to depend on the fact that nerve fibers are not electrically excitable until they are provided with a medullary sheath of a certain width, while they can conduct voluntary impulses at an earlier stage (Erb).

The researches of Botazzi and Ioteyko explain the loss of faradic contractility and the slowness of contraction (modal change). They have shown that in each muscle fiber there are two contractile substances, a fibrillar and protoplasmic, which react differently to the electrical current. The fibrillar, when stimulated, gives the quick response characteristic of the normal muscle; the protoplasmic, on the other hand, reacts slowly, as is seen in degenerated muscles, and requires a stronger current than does the fibrillar. Degenerated muscles show a decrease of fibrillary substance and increase of the protoplasm or sarcoplasm. It will hence be seen that in degenerated muscles the contraction must be of the protoplasm type, *i. e.*, slow; again, as the protoplasmic substance is less irritable, and having the characteristics of unstriated muscle, it is not irritated by the faradic current.[1] The resemblance of degenerated muscle to unstriated or involuntary muscle fiber

[1] This view has lately been combated by Bienfait, Jour. de Neurologie, 1908, vol. xiii, No. 3.

also explains the serial change, as in such muscles, apparently, AnClC is greater than KClC normally. Biederman has, however, shown that this is apparent and not real, and depends in the formation of virtual kathodes in the region of the anode (p. 112). Thus, if a small kathode is used to stimulate the circular muscle of the intestine, a slight elevation

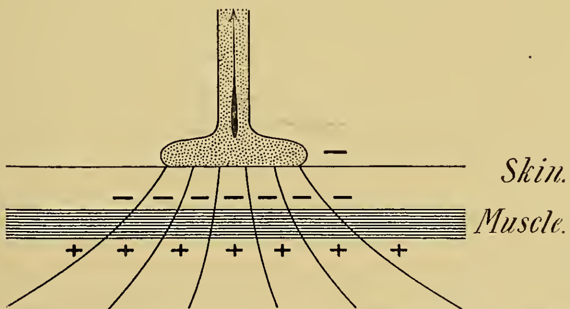
Fig. 101



Electrodes applied to the skin over a nerve trunk or muscle. The polar area is anelectrotonic and the peripolar katelectrotonic. The former condition therefore preponderates, since the current here is more concentrated. (Waller.)

occurs immediately beneath it, while the zone around the kathode shows no sign of contraction. At the anode, however, the polar zone remains inert, and the peripolar region forms a circular swelling due to contraction. The region of relaxation at the polar region is, however, so small that it is frequently overlooked (Figs. 101 and 102).

Fig. 102



The conditions of Fig. 101 are reversed, the polar zone corresponding in this case to the kathode. (Waller.)

May[1] has shown that voluntary muscle, when degenerated, acts in the same way. His experiments were made on rabbits in whom a nerve trunk was injured; then after degeneration had taken place, the affected muscles were exposed and tested. He found that when an ordinary sized electrode was employed to stimulate the muscle by the polar method (p. 161), AnClC was obtained with a weaker current than

[1] On the Supposed Reversal of the Law of Contraction in Degenerated Muscle, Brain, 1902, p. 133.

KClC was, but when a very fine needle-point electrode was used, the normal contraction was given, *i. e.*, KClC > AnClC. He explains this as due to the formation of virtual kathodes and anodes (p. 112) as follows: "The current enters a few fibers at the anode, and thence spreads in all directions through the muscle. Every muscle fiber will, therefore, have anodic and kathodic points, but as the current is constantly spreading, the kathodic will be more diffused than the anodic points (Fig. 101); and given a certain rise in excitability, the widespread peripolar kathodic excitation may be more easily observable than the very limited anodal relaxation or absence of effect." When, however, the fine-pointed electrodes were employed, this diffusion and consequent formation of virtual kathodes does not take place, and to produce contraction required a stronger current than with the kathode. In other words, when the kathode is applied to the muscle its effect is limited to its immediate neighborhood (Fig. 102), while if the anode is applied the kathodes will be peripolar (Fig. 101), and will be widely diffused through the muscle, and a greater mass of muscle will be under kathodic influence and fibers not yet degenerated will be influenced, hence the greater contraction.

Weiner[1] explains the reversal of contraction by the action of the virtual kathodes upon the more excitable muscle ends (Doumer's "longitudinal reaction," p. 148). Thus, when the anode as the exciting electrode is applied to the middle of the muscle, the virtual kathodes, being diffused as described above by May, excite the distal ends of the muscle; but when the kathode is the exciting electrode, the more excitable muscle ends are affected very slightly by the virtual anodes there formed. In normal muscle, however, the more excitable point of the muscle being at the motor point, the virtual kathodes formed at the distal end of the muscle will find relatively few excitable points.

THE MYOTONIC REACTION AND ITS SIGNIFICANCE

This phenomenon, so named by Erb, occurs only in *Thomsen's disease* or in *myotonia congenita*, and when combined with increased mechanical irritability, is pathognomonic of that disorder. It consists of a normal reaction of the nerves to both the faradic and galvanic currents. The muscles, when directly stimulated with a minimal faradic current (the weakest current that will cause a contraction), react normally; but when the current strength is increased, the contraction becomes tetanic in character and persists as a tonic contraction for some time (as much at times as twenty seconds) after the stimulus has ceased and then gradually subsides. Strong faradic currents also, in some cases, produce irregular undulating contractions. When the muscles are directly stimulated with the galvanic current, only closure contractions are produced, but AnClC = KClC, and the contractions are slow, tonic, and prolonged, like those produced with the faradic current. These

[1] Quoted by Cohn, Electrodiagnosis and Therapeutics, p. 122.

prolonged contractions differ from those seen as part of the DeR, in that they are produced both by the faradic and galvanic currents, often more markedly with the former. Another phenomenon, at times observed in these cases, is what are sometimes termed Erb's waves. They consist of wave-like movements in the muscle passing from the kathode to the anode occurring when a strong galvanic current is caused to pass without interruption through it.

MYOCLONIC CONTRACTIONS

These are caused only by faradic stimulation with the rapidly interrupted current. They consist of rapid clonic contractions during the period of stimulation, instead of the tetanic contraction which should be so produced. They are of infrequent occurrence and indicate general muscular weakness, and sometimes occur in cases of progressive muscular atrophy, especially in muscles which functionally are as yet unaffected. When present they may be of assistance in medicolegal cases in differentiating actual from simulated weakness; their absence, however, is of no negative value.

Table Showing the Connection between Pathological States of the Motor Tract and Muscles and their Electrodiagnostic Symptoms (Functional Disorders are Included).

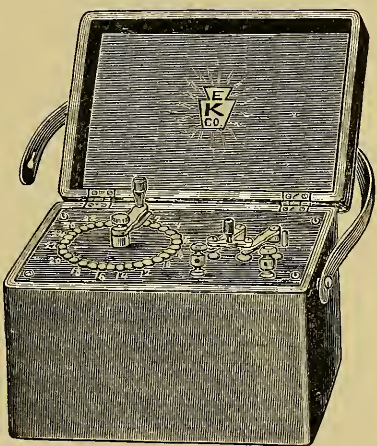
Seat of the lesion and the disease.	Electrical reactions.
Brain cortex and the pyramidal tracts (central neuron), *Cu-Py*, Fig. 94, viz.: Cerebral apoplexy and the resultant paralysis; tumor; abscess; transverse or compression myelitis (muscles supplied by nerves arising from segments below the seat of the lesion); lateral sclerosis; hysterical paralysis.	Normal usually. If paralysis is of long duration, sometimes slight diminution of excitability.
Pyramidal tracts and the cells of the anterior horns of the cord (central and peripheral neurons). *Py-Sc*, Fig. 94, amyotrophic lateral sclerosis.	In non-atrophied muscles—normal. In atrophied muscles—either quantitative decrease or DeR (usually partial).
Cells of the anterior horns of the cord and bulbar motor nuclei (peripheral neuron) (Fig. 94).	
a, acute poliomyelitis; transverse myelitis, tumor, hemorrhage, localized meningitis, syringomyelia (muscles supplied by nerves from the affected segments when the gray matter of the cord is involved); glossolabiolaryngeal paralysis.	*a*, various degrees of DeR, in acute poliomyelitis most often complete.
b, progressive muscular atrophy.	*b*, quantitative decrease in early stages. Various degrees of DeR in the later. This may also apply to syringomyelia, localized meningitis, and glossolabiolaryngeal paralysis.
c, myasthenia gravis.	*c*, myasthenic reaction.
Peripheral nerves (peripheral neuron), *PU*, Fig. 94: Neuritis from various causes, as rheumatic, traumatic, or toxic; progressive neuritic muscular atrophy.	Quantitative decrease in mild cases. Various degrees of DeR in the more severe ones.
Muscles. *M*, Fig. 94.	
a, myopathics or dystrophies.	*a*, normal or quantitative decrease.
b, myotonia congenita.	*b*, myotonic reaction.
c, tetany.	*c*, quantitative increase.

[1] Placed here for convenience; it is understood that tetany is not a disease limited to the muscles in the sense that the dystrophies are.

METHODS OF EXAMINATION

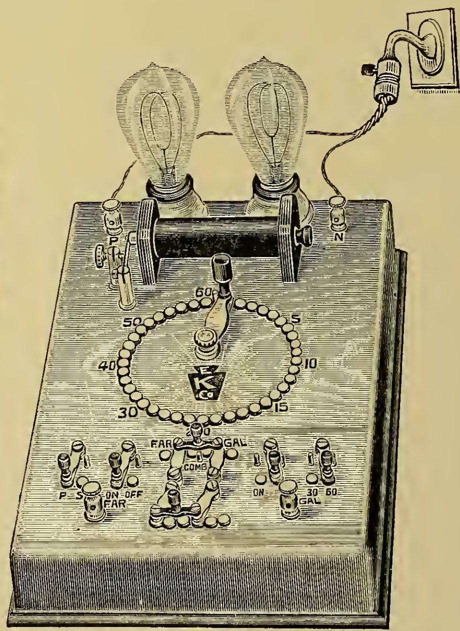
The following apparatus is essential for a thorough electrodiagnostic examination, viz.: A galvanic battery of from thirty to fifty cells (Fig. 103) or other source of constant current, as in Fig. 104, which is designed for use on an electric light circuit; a current controller or rheostat with which the current strength can be altered gradually, such as is shown in Fig. 104, or, what is better, that shown in Fig, 105. A milliamperemeter with shunt or scales of different capacity (Fig. 46) should also be in the circuit, and the battery should have a commutator, as shown on right hand side of Fig. 93, so that the poles can be changed without moving

Fig. 103



Keystone portable galvanic battery.

Fig. 104



Galvanic faradic and lamp controller.

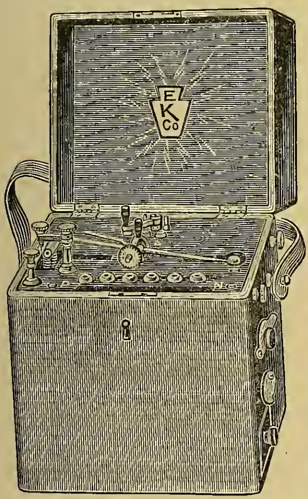
the electrodes. A faradic battery supplied by dry cells, with a standard coil and rapid and slow interrupters, should also be at hand (Fig. 106). The coil should either have an arbitrary scale so that the degree of approximation of the secondary to the primary coil can be determined or regulated by the metallic tube described on pages 92 and 93. If desired, either a portable combined faradic and galvanic battery (Fig. 107), or a stationary table or wall plate, as shown in Figs. 108 and 109. With

these should be used a large indifferent electrode,[1] such as shown in Fig. 110. Other forms of electrodes are shown in Figs. 112 to 115.

Fig. 105

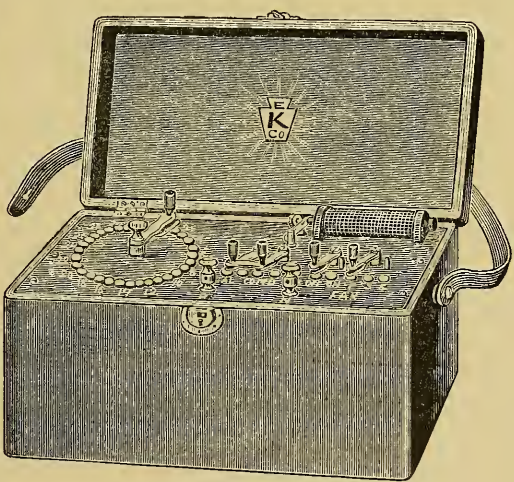
The Massey current controller.

Fig. 106



Faradic battery with slow and rapid interrupters.

Fig. 107

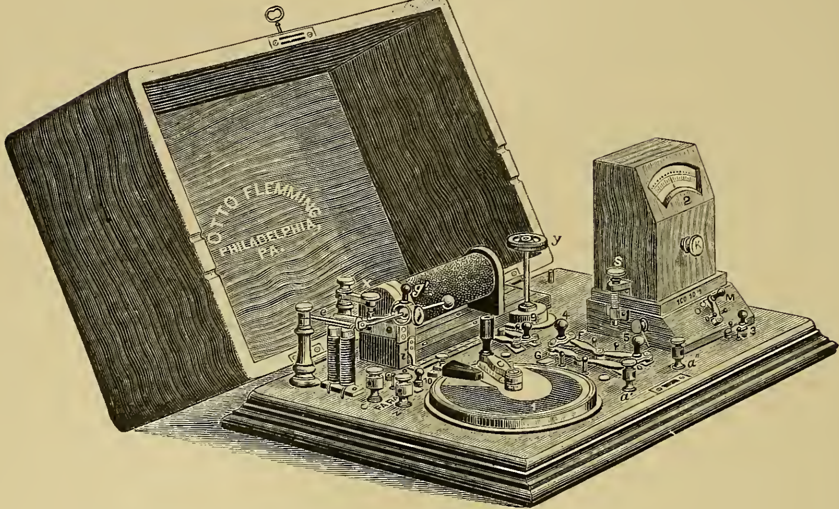


Portable combined galvanic and faradic batteries.

The position of the patient is of importance. He should be placed in a good light and the muscles to be examined should be relaxed. A sitting

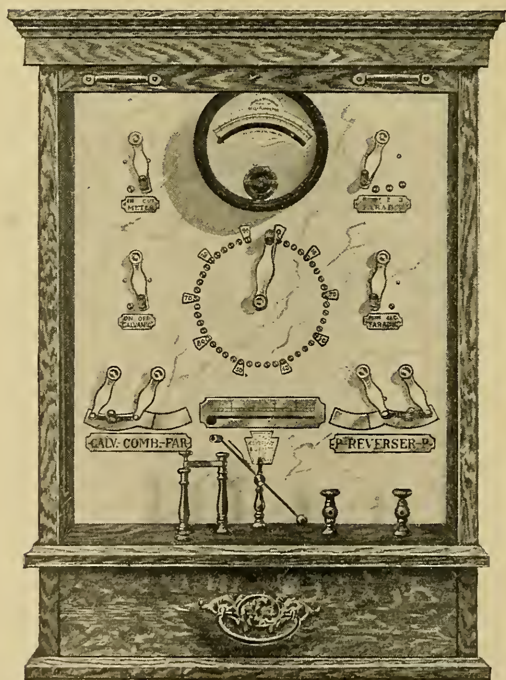
[1] As it is important for the indifferent electrode to remain in the same position during the examination, one that can be fastened to the body, as Fig. 111, is preferable.

Fig. 108



Flemming table plate for battery current.

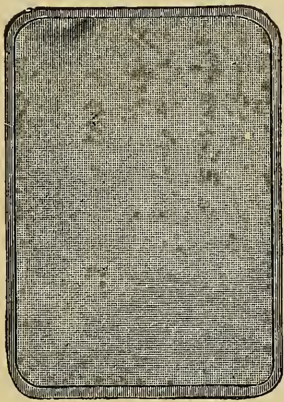
Fig. 109



Keystone electrotherapeutic wall plate for use with 110-volt direct current.

posture is best for examination of the head, neck, and upper extremities, the latter resting upon a table or the knee of the examiner. Trunk muscles may be examined either in the recumbent or sitting posture

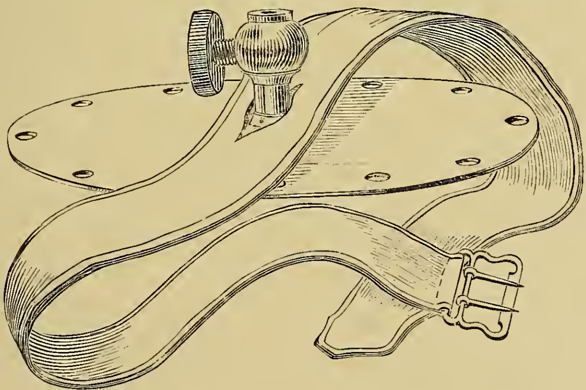
Fig. 110



Felt-covered electrode with soft rubber back.

For the legs the preferable position is lying down, although it may be done with the patient sitting and the leg resting on a chair. The muscles of the buttocks may be tested while the patient is standing.

Fig. 111

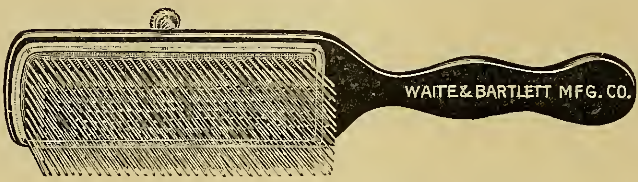


Adjustable electrode, with band for the body. (Kidder.)

The examination to determine the presence of DeR must be conducted by the polar method (p. 111), the large flat electrode, well moistened, being placed upon some indifferent and remote point, preferably the sternum or sacrum. The back of the neck may be also employed as a site, but when so placed flashes of light, metallic taste,

and vertigo are caused, and it should only be selected when neither of the other two locations is convenient. This electrode must remain in exactly the same spot during the examination, hence one like that shown

Fig. 112

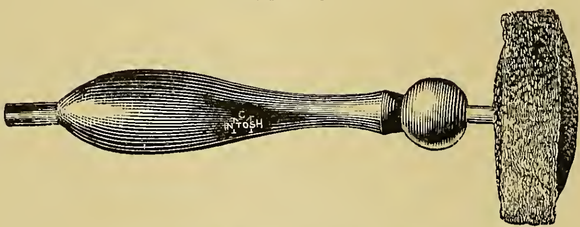


Hair brush electrode.

in Fig. 111, that can be fastened to the body, is preferable if it can be obtained.

The small electrode (Fig. 115), similarly moistened, is placed over the nerve or muscle to be examined (Fig. 116). In the case of the muscle it should usually be placed over the *motor points*. These are points

Fig. 113



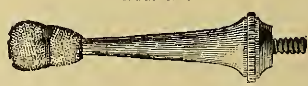
Universal handle, with sponge-covered disks.

upon the surface of the body from which the respective muscles can be excited most easily. They correspond to the points of entrance into the muscles of their motor nerve branches. The nerves will be found to be most excitable when they lie nearest to the surface of the body. When a healthy nerve is stimulated all the muscles supplied by

Fig. 114

Universal handle, with interrupter.

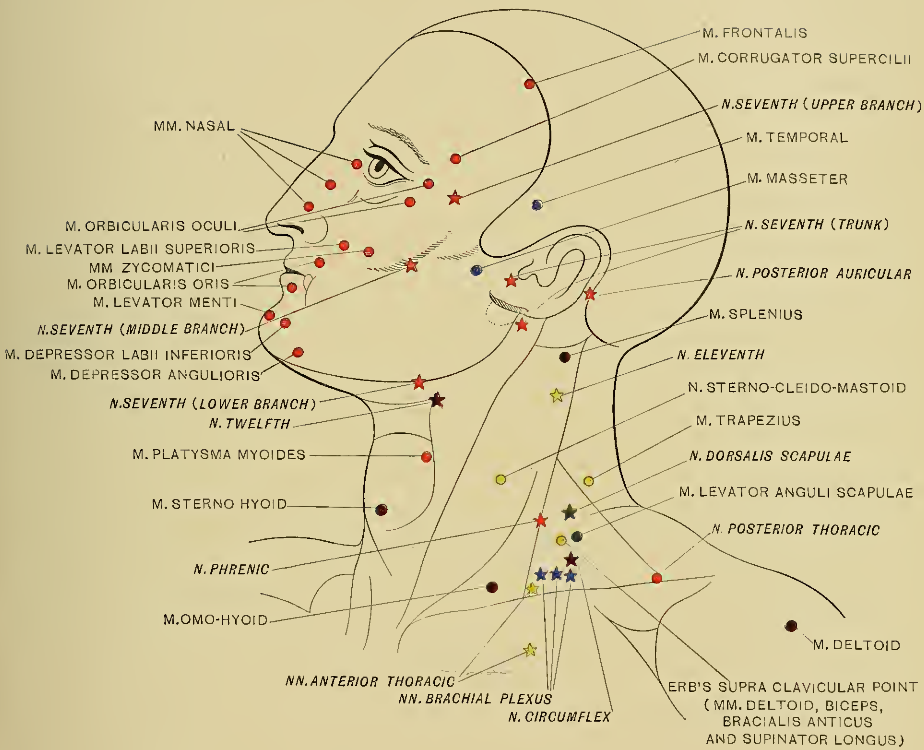
Fig. 115



Electrode, Erb's pattern.

this nerve below the point of stimulation contract (in direct excitation) (pp. 163 to 170), when a muscle or muscle segment (as the deltoid, for example, Plate II) is stimulated, only the muscle or segment responds (direct excitation). Von Ziemssen has mapped out both the motor points of the muscles and nerves which are shown in Plates I to VI,

PLATE I

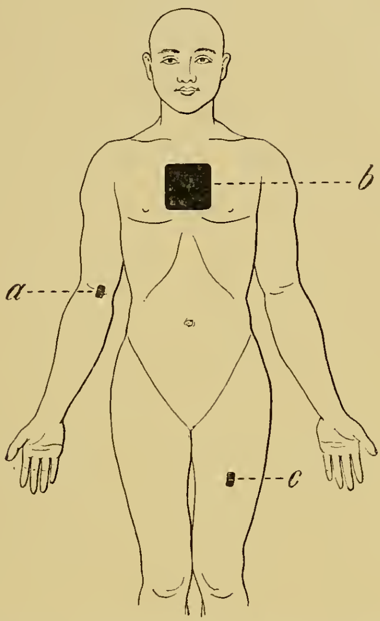


Motor Points of the Face and Neck.

(From Mosher's Electro-Diagnosis.)

in which the nerves are indicated by stars and the muscles supplied by them by circles of a corresponding color. They should be accessible for reference during the examination.

Fig. 116



Position of electrodes in testing quadriceps muscle. In testing other muscles the indifferent electrode remains in the same position and the active electrode is placed over the motor points of the other muscles in turn. If the nerve is being tested it is placed over the nerve: *a*, small active electrode over the median nerve; *b*, large electrode over the chest; *c*, small electrode over the motor point of the quadriceps femoris.

THE MOTOR POINTS[1]

Fifth Nerve.—*Action.*—Elevation and forward and lateral movement of the lower jaw.

Motor Points for the Muscles.—*Masseter.*—In the sigmoid notch of the lower jaw, just below the zygoma. Moderately strong current required.

Temporal.—In a perpendicular line through the zygoma, a finger-breadth within the border of the hair. Moderately strong current required.

Seventh Nerve.—*Action.*—Drawing of the face to the stimulated side and closing of the eyelid. The frontalis and corrugator supercilii often contract very weakly or not at all.

Motor Points.—(1) In the angle between the mastoid process and the ramus of the lower jaw.. The electrode is to be pushed upward and

[1] From J. M. Mosher's Electrodiagnosis.

forward against the lower half of the ear and border of the jaw. (2) In the depression just above the tragus. This point is not constant and is better for excitation of the middle and lower branches.

Posterior Auricular Nerve.—*Action.*—Retraction of the ear and scalp.

Motor Point.—At the base of the mastoid process level with or slightly above the middle of the ear.

Upper Branch of the Seventh Nerve.—*Action.*—Wrinkling of the forehead and eyebrow, and closing of the eyelids.

Motor Point.—At the outer end of the superciliary ridge.

Motor Points for the Muscles.—*Frontalis.*—At the outer and upper angle of the forehead near the border of the hair. Painful. The test should be made quickly.

Corrugator Supercilii.—Over the eyebrow, a little inside the point for the upper facial branch.

Orbicularis Oculi.—Two points at the outer angle of the orbit.

Middle Branch of the Seventh Nerve.—*Action.* — Expression of laughing, wrinkling of the nose and of the upper lip, or pouting of the lips.

Motor Point.—At the junction with the zygoma of a perpendicular line dropped from the outer angle of the orbit.

Motor Points for the Muscles.—*Nasal: Compressor, Pyramidalis, and Dilator.*—At the inner angle of the eye near the root of the nose.

Levator Labii Superioris Alæque Nasi.—On the cheek just outside the nasal fold, level with the nares.

Zygomatici.—On the cheek outside the point for the levator.

Orbicularis Oris.—Upper portion: A finger-breadth above the lip, inside the outer angle of the mouth.

Lower Portion: Near the lip and somewhat nearer the middle line than the point for the upper portion.

Lower Branch of the Seventh Nerve.—*Action.*—Elevation of the chin, pouting of the under lip, and retraction of the angle of the mouth downward and outward.

Motor Point.—At the border of the lower jaw just back of the groove for the facial artery.

Motor Points for the Muscles.—*Levator Menti.*—Near the middle line of the chin just above the border of the lower jaw.

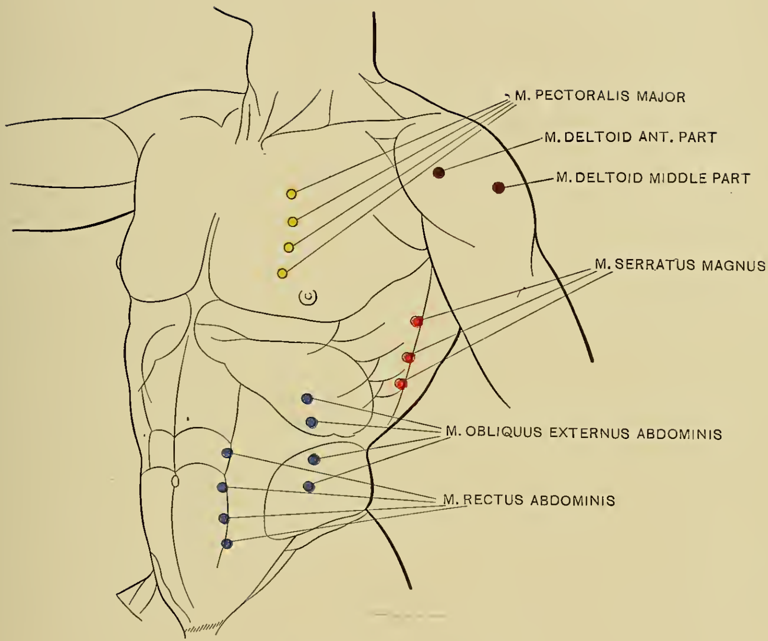
Depressor Labii Inferioris (Quadratus Menti).—A little outside and above the point for the levator.

Depressor Anguli Oris. (Triangularis Menti).—Generally near the lower border of the jaw, a little outside the point for the depressor labii inferioris.

Platysma Myoides.—In the anterior cervical triangle level with the larynx.

Eleventh Nerve.—*Action.*—Extension of the head, and elevation and rotation of the chin toward the opposite side.

PLATE II



Motor Points of the Trunk.

(From Mosher's Electro-Diagnosis.)

Motor Point.—About two finger-breadths below the upper angle of the posterior cervical triangle, near the trapezius.

Motor Points for the Muscles.—*Sternocleidomastoid.*—At about the centre of the muscle.

Trapezius.—At about the centre of the anterior edge of the muscle.

Twelfth Nerve.—*Action.*—Movements of the tongue.

Motor Point.—Close behind and above the hyoid bone.

Motor Points for the Muscles.—The intrinsic muscles of the tongue. Direct stimulation.

Omohyoid.—Over the lower belly, between the insertions of the sternocleidomastoid.

Sternohyoid.—At the middle point of the belly of the muscle.

Cervical Nerves (External Branches of Posterior Division).—*Action.*—Drawing the head backward and downward.

Motor Point for the Muscle.—*Splenius Capitis.*—Over the belly of the muscle close under the mastoid process.

Phrenic Nerve.—*Action.*—Ballooning of the epigastrium and a noisy rush of air into the air passages.

Motor Point.—Behind the edge of the sternocleidomastoid, between the upper and middle thirds, sometimes farther below. The electrode is to be pushed beneath the muscle.

Brachial Plexus.—*Action.*—Depending on the point, usually the distribution of the median and circumflex; flexion of the hand and fingers, elevation of the arm from the thorax, etc.

Motor Point.—Mainly in the whole lower and inner third of the supra-clavicular fossa; parts also may be easily stimulated outward therefrom.

Dorsalis Scapulæ Nerve (Third, Fourth, and Fifth Cervical Nerves.)—*Action.*—Elevation of shoulder-blade with retraction toward spinal column.

Motor Point.—In the middle line of the posterior cervical triangle, three finger-breadths above the clavicle.

Motor Points for the Muscles.—*Rhomboids, Major and Minor.*—Direct stimulation, with intact trapezius, impossible.

Levator Anguli Scapulæ.—A finger-breadth below the point for the nerve and slightly behind it. Not easily differentiated from the motor point for the nerve, inducing simultaneous contraction of the rhomboids.

Long or Posterior Thoracic Nerve.—*Action.*—Movement of the shoulder-blade outward and forward, or visible contraction of the digitations of the serratus magnus.

Motor Point.—Close above the clavicle in front of the edge of the trapezius.

Motor Points for the Muscles.—*Serratus Magnus.*—In the midaxillary line, particularly at the level of the sixth rib.

Suprascapular Nerve.—*Action.*—Rotation of the humerus.

Motor Points for the Muscles.—*Supraspinatus.*—Near the outermost angle of the supraspinous fossa, and only attainable when the trapezius is atrophied.

Infraspinatus.—At about the middle of the infraspinous fossa. Not easily stimulated.

Anterior Thoracic Nerves.—*Action.*—Adduction of the arm to the thorax.

Motor Points.—(1) Close above and behind the clavicle, near the outer border of the sternocleidomastoid. (2) Just below the clavicle at the upper border of the pectoralis major. The electrode is to be pushed deeply, with the patient's arm hanging, and a moderately strong current is to be used.

Motor Points for the Muscles.—*Pectoralis Major.*—Several, upon the anterior thoracic wall over the chondrocostal articulations.

Lower Subscapular Nerve.—*Action.*—Rotation of the humerus.

Motor Points for the Muscles.—*Teres Major.*—Occasionally upon the muscle in the axilla.

Long Subscapular Nerve.—*Action.*—Adduction backward and downward of the arm.

Motor Point for the Muscle.—*Latissimus Dorsi.*—At the anterior edge of the muscle, level with the angle of the scapula.

Erb's Supraclavicular Point.—*Action.*—Backward elevation of the arm from the thorax, and strong flexion at the elbow in position of pronation.

(Muscles: Deltoid, biceps, brachialis anticus, and supinator longus.)

Motor Point.—Two finger-breadths above the clavicle and one finger-breadth behind the border of the sternocleidomastoid.

Circumflex Nerve.—*Action.*—Elevation of the arm backward from the thorax.

Motor Point.—In the middle line of the posterior cervical triangle, two finger-breadths above the clavicle.

Motor Points for the Muscles.—*Deltoid.*—Direct stimulation of the anterior and posterior bundles.

Teres Minor.—Occasionally upon the muscle in the axilla.

Musculocutaneous Nerve.—*Action.*—Flexion of the forearm.

Motor Point.—Two finger-breadths below the anterior axillary fold, at the inner border of the biceps.

Motor Points for the Muscles.—*Biceps.*—Over the belly of the muscle.

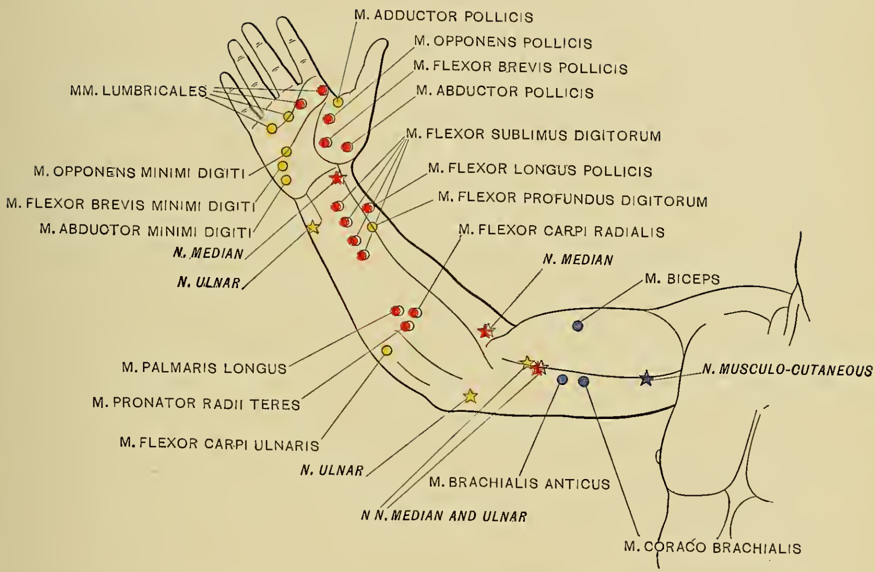
Coracobrachialis.—(1) At the inner border of the biceps, just below the centre. (2) At the outer border of the biceps, three finger-breadths above the elbow. Push the electrode, which should be small, under the biceps muscle.

Brachialis Anticus.—Behind the inner side of the biceps tendon in the lower third of the arm. Not easily stimulated when the biceps is intact.

Median and Ulnar Nerves.—The ulnar and median nerves are easily stimulated simultaneously throughout the groove at the inner side of the biceps muscle (sulcus bicipitalis internus).

The best position of the arm for the stimulation of these nerves and their muscles is one of very slight flexion, with greatest possible relaxation of the muscles. Only a weak current is needed.

PLATE III



Motor Points of the Arm and Hand, Flexor Surface.

(From Mosher's Electro-Diagnosis.)

In the hand the thenar and hypothenar muscles are most easily stimulated, and the lumbricales are often difficult to reach. The reaction of the forearm and hand differ greatly in different people.

Median Nerve.—*Action.*—Pronation of the forearm, flexion and abduction of the hand, opposition and flexion of the thumb, flexion of the second and third phalanges of the fingers.

Motor Points.—(1) In the middle of the elbow-joint, usually directly outside of the biceps tendon. (2) In the middle of the wrist-joint, between the tendons of the flexor carpi radialis and palmaris longus, or at the ulnar border of the latter.

Motor Points for the Muscles.—*Pronator Radii Teres.* Three finger-breadths below the elbow-joint, at the outer margin of the bundle of flexor muscles.

Palmaris Longus.—A finger-breadth below the point for the pronator radii teres, and slightly nearer the middle line. Often difficult to differentiate from the flexor carpi radialis

Flexor Carpi Radialis. — Directly below the point for the pronator radii teres, and a finger-breadth toward the radial side of the forearm.

Flexor Sublimis Digitorum.—Several, in the middle and lower thirds of the forearm, in a line from the internal condyle to the middle of the palm, and also toward the radial border of the forearm.

Flexor Longus Pollicis.—Four finger-breadths above the wrist on the radial border.

Thenar Muscles; Opponens Pollicis, Flexor Brevis Pollicis, Abductor Pollicis.—The points lie in a slightly curved line on the ball of the thumb.

Third and Fourth Lumbricales.—In common with the points for the interossei supplied by the ulnar nerve.

Ulnar Nerve.—*Action.*—Ulnar flexion of the hand and the first phalanges of the fingers; adduction of the thumb.

Motor Points.—(1) Between the inner condyle and the olecranon, about one finger-breadth above the condyle. (2) On the ulnar side of the forearm a little above the wrist.

Motor Points for the Muscles.—*Flexor Carpi Ulnaris.*—On the border of the forearm between the flexor and extensor surfaces, one hand-breadth below the internal condyle.

Flexor Profundus Digitorum.—In the middle of the forearm, level with the principal point for the flexor sublimis digitorum, toward the radial border. Not easily differentiated from the flexor sublimis digitorum.

Adductor Pollicis.—On the dorsal surface in the angle between the thumb and index finger. Usually in combination with other small muscles of the thumb.

Hypothenar Muscles; Adductor Minimi Digiti, Flexor Brevis Digiti Minimi, Opponens Minimi Digiti.—In a slightly curved line on the ball of the little finger.

Lumbricales and Interossei.—In the interosseous spaces on the back of the hand, somewhat nearer the wrist than the bases of the fingers.

Musculospiral Nerve.—*Action.*—Extension of forearm, hand, and fingers, with supination.

Motor Point.—Slightly outside the point between the external condyle and the insertion of the deltoid. The electrode is to be pushed firmly and deeply between the biceps and triceps muscles, against the musculospiral groove. The application is sometimes painful and difficult.

Motor Points for the Muscles.—*Triceps.*—Three points for the three heads usually in a horizontal line a hand-breadth above the olecranon. The long head may be also stimulated two finger-breadths below the posterior axillary fold.

Supinator Longus.—Close above and in front of the external condyle.

Extensor Carpi Ulnaris.—Close to the posterior border of the ulna on its radial side, a hand-breadth below the olecranon.

Extensor Indicis.—Slightly above the middle of the forearm on a line from the external condyle to the base of the index finger.

Extensor Communis Digitorum.—A series on an oblique line from the point for the extensor carpi ulnaris to the point for the extensor indicis, particularly at the middle point of this line.

Extensor Minimi Digiti.—One or two finger-breadths inside and slightly above the point for the extensor indicis.

Extensor Carpi Radialis Longior.—Three finger-breadths below the external condyle, in the groove behind the supinator longus.

Extensor Carpi Radialis Brevior.—Two or three finger-breadths below the point for the long radial extensor. Not easily differentiated from the extensor communis digitorum.

Supinator Brevis.—Below and within the external condyle. A difficult muscle to stimulate, unless in atrophy of the overlying muscles. Cohn notes that in many persons there is a response to only one faradic pole, whereas the other at the same point elicits a response of some other muscle, as one of the extensors of the hand.

Extensor Ossis Metacarpi Pollicis.—Between the points for the extensor indicis and the extensor primi internodii pollicis.

Extensor Primi Internodii Pollicis (Extensor Pollicis Brevis).—In the centre of the extensor surface of the forearm, three finger-breadths above the wrist.

Extensor Secundi Internodii Pollicis (Extensor Pollicis Longus).—In the centre of the extensor surface of the forearm, one finger-breadth above the wrist.

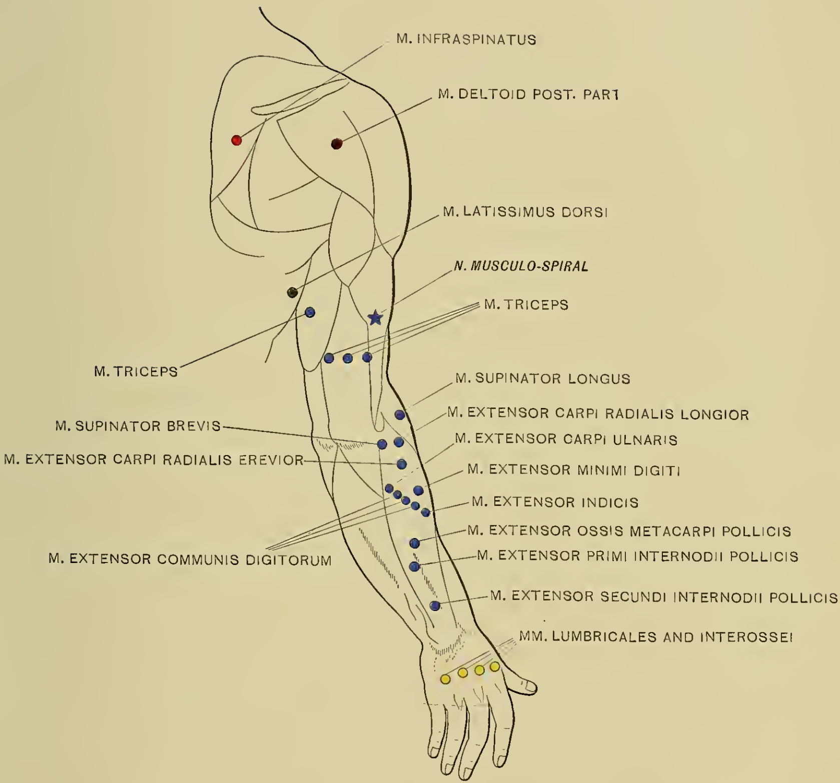
Upper Intercostal Nerves.—*Action.*—Movements of the ribs.

Motor Points.—On the upper borders of the intercostal spaces. Use a small electrode. Electrical stimulation unimportant.

Lower Intercostal Nerves.—*Action.*—Retraction of the abdomen.

Motor Points for the Muscles.—*Obliquus Externus Abdominis.*—Several, over the belly of the muscle, between the costal margin and the crest of the ilium.

PLATE IV



Motor Points of the Arm and Hand, Extensor Surface.

(From Mosher's Electro-Diagnosis.)

Rectus Abdominis.—Several, along the outer border of the muscle, most easily below the umbilicus.

Obturator Nerve.—*Action.*—Adduction of thigh.

Motor Point.—At the outer end of the horizontal ramus of the pubis.

Motor Points for the Muscles.—*Adductors Longus, Brevis, and Magnus.* —Several, on the inner surface of the thigh, at the junction of the upper and middle thirds.

Anterior Crural Nerve.—*Action.*—Extension of the leg.

Motor Points.—(1) Above and behind the middle of Poupart's ligament. Deep pressure with the electrode. (2) In Scarpa's triangle just outside of the femoral artery.

Motor Points for the Muscles.—*Sartorius.* Over the belly of the muscle a hand-breadth below Poupart's ligament.

Quadriceps Extensor Femoris.—At the junction of the upper and middle thirds of the thigh at the inner border of the rectus muscle.

Vastus Internus.—A hand-breadth above the patella on the inner side of the muscular bundle. Easily stimulated.

Vastus Externus.—On the outer side of the muscular bundle, about two hand-breadths above the patella.

Rectus Femoris.—At the middle point of the anterior surface of the thigh, just below the point for the quadriceps extensor.

Superior Gluteal Nerve.—*Action.*—Extension of hip and abduction of thigh.

Motor Points for the Muscles.—*Gluteus Medius.*—Between the trochanter major and the crest of the ilium. This test is much more satisfactorily made when the patient is made to stand on the limb not under examination and support himself by his hands.

Tensor Vaginæ Femoris.—High upon the outer border of the thigh, just in front of the trochanter major.

Small Sciatic Nerve.—*Action.*—Extension, abduction, and rotation of thigh outward; elevation and adduction of the buttock.

Motor Points for the Muscles.—*Gluteus Maximus.*—Several points over the belly of the muscle.

Great Sciatic Nerve.—*Action.*—Flexion of the leg and plantar flexion of the foot.

Motor Point.—Midway between the trochanter major and the tuberosity of the ischium in the gluteofemoral crease, or just below it.

Motor Points for the Muscles.—*Semitendinosus and Semimembranosus.* —At the middle of the inner border of the thigh. At a common point just above the former of the long head of the biceps may be also simultaneously stimulated.

Biceps.—At the outer side of the thigh below the level of the point for the semimembranosus and semitendinosus.

Internal Popliteal (Tibial) Nerve.—*Action.*—Flexion and wrinkling of the skin of the sole and plantar flexion of the toes. The wrinkling of the skin of the sole is particularly characteristic.

Motor Points.—(1) Just above the middle of the popliteal space. (2) Between the internal malleolus and the tendon of Achilles.

Motor Points for the Muscles.—*Gastrocnemius.*—Over each head of the muscle, a hand-breadth below the knee.

Soleus.—Over the body of the muscle not covered by the gastrocnemius; the outer head also a hand-breadth higher than the inner. The preliminary test of the gastrocnemius reveals its outlines and facilitates the test of the soleus.

Flexor Longus Digitorum.—A hand-breadth above the internal malleolus.

Flexor Longus Hallucis.—Two or three finger-breadths above the external malleolus, close against the fibula. Deep pressure with the electrode.

Interossei.—Analogous with the points on the hand.

Abductor Minimi Digiti.—On the outer border of the foot between the middle and posterior thirds.

External Popliteal (Peroneal) Nerve.—*Action.*—Dorsal flexion of the foot and extension of the toes.

Motor Point.—At the outer angle of the popliteal space, close to the inner border of the tendon of the biceps. The best position for the examination of the leg nerves and muscles is attained when the patient is recumbent, with the knee slightly flexed. Pressure is to be applied directly.

Motor Points for the Muscles.—*Tibialis Anticus.*—Two finger-breadths below the external tuberosity of the tibia, close to the crest. In children at the junction of the upper and middle thirds of the leg.

Peroneus Longus.—Two or three finger-breadths below the head of the fibula.

Peroneus Brevis.—Half-way between the head of the fibula and the external malleolus. A moderately severe current required.

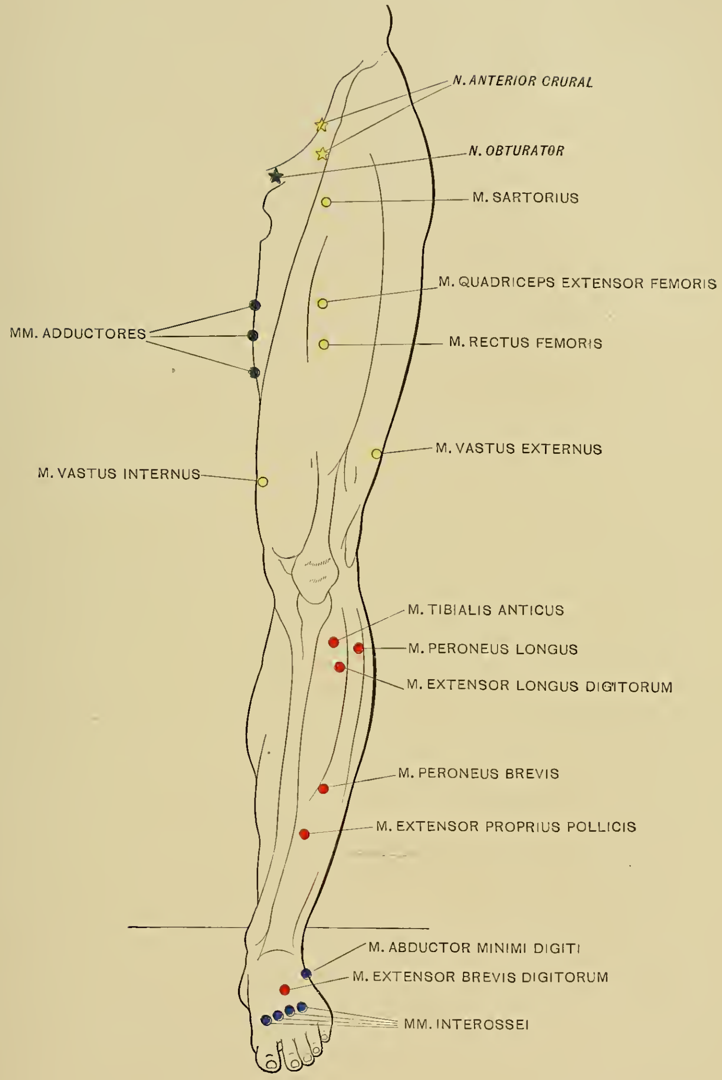
Extensor Longus Digitorum.—Three finger-breadths below the external tuberosity of the tibia. In children, at the junction of the upper and middle thirds, directly outside the point for the tibialis anticus.

Extensor Proprius Pollicis.—Close to the outer edge of the crest of the tibia, a variable distance (two to four finger-breadths) above the ankle.

Extensor Brevis Digitorum.—Between the external malleolus and the base of the toes.

While the points indicated in the diagrams are correct for most individuals, anatomical peculiarities may exist in others which cause the motor point to be in a different location from that indicated. It is therefore well in all cases to move the electrode to other points in the vicinity of the supposed motor point to determine if it really is the most irritable place. If it is not, a current strength which will give a minimal contraction when the electrode is there placed, will give a stronger one when the more irritable location is stimulated, and this would be the motor point in this particular case. In this connection

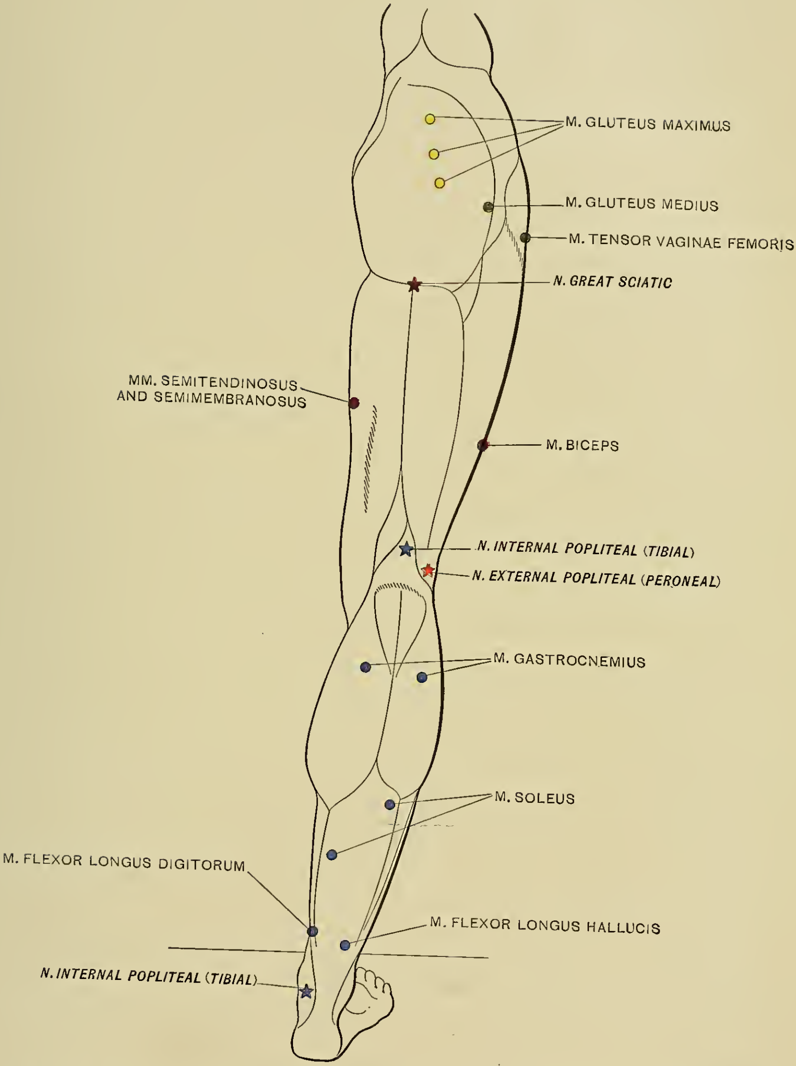
PLATE V



Motor Points of the Thigh and Leg, Anterior Surface.

(From Mosher's Electro-Diagnosis.)

PLATE VI



Motor Points of the Thigh and Leg, Posterior Surface.

(From Mosher's Electro-Diagnosis.

the fact that in degenerating muscles the most irritable point may move toward the distal end of the muscle (when the muscle fibers join the tendon) must be remembered (Doumer's longitudinal reaction, p. 148). In order to be sure that the proper nerve or muscle is being stimulated it is important that the movements produced respectively by their irritation or contraction be known. These are detailed on pages 163 to 170, as are also remarks concerning difficulties and peculiarities which may be encountered in the examination of certain muscles and preferable methods of so doing.

FARADIC EXAMINATION

The examination should be begun by testing the irritability of the nerve and muscles with the faradic current, for if they respond equally as well as the corresponding normal muscles when so stimulated, we know that DeR is not present and that the paralysis is due either to a lesion in the central neuron or is functional (see table, p. 157); consequently further examination is unnecessary. The proper method of ascertaining this fact is as follows: If the paralysis is confined to one side, we first ascertain the weakest current that will cause a contraction of the corresponding nerve and muscles of the normal limb (minimal contraction). This is done by placing the electrodes as mentioned above (p. 161), and preferably employing the secondary current with the slow interrupter; we then, beginning at zero, gradually slide the secondary coil over the primary until the minimal contraction is produced.[1] The distance that the secondary coil covers the primary when contraction first takes place must be carefully noted. The diseased nerve and muscles are then treated in the same way, when it should be noted if a less amount of secondary coil covers the primary, when the minimal contraction occurs, denoting increased excitability, or if a greater amount is required, denoting lessened excitability, or if no contraction occurs. If the rapid interrupter is employed the current may be interrupted by means of the interrupting handle (Fig. 114).

Care must be taken that the exciting electrode is placed in a similar location on each corresponding muscle, for as different parts of a muscle are more excitable than others, it can readily be seen that if this is not done, no accurate basis of comparison exists. This location preferably should be the motor point (pp. 162 and 163). Also as variations in pressure cause a difference in the degree of contraction, it is important that a similar degree be exerted in each case.

In cases where the same muscles are paralyzed in both limbs, no such basis of comparison as above described exists. In such cases we are obliged to rely either on testing our own or the muscles of some other

[1] In some portable batteries the current is strengthened by withdrawing the metal tube which covers the soft iron core of the primary coil (tube of Duchenne, p. 93). Such an arrangement is not either so satisfactory or accurate for diagnostic purposes as the method of approaching or withdrawal of the secondary from the primary coil. (Sledge coil of Du Bois Reymond, p. 92.)

normal person and comparing the amount of coil required to produce the minimal contraction.[1] It should also be noted if the ability to contract is easily exhausted, and if so, whether it returns after a period of rest (myasthenic reaction). If it is found that there is either absence of or lessened faradic excitability in either the nerve, muscle, or both, we should then proceed to test them with the galvanic current

GALVANIC EXAMINATION

The electrodes used in this examination should be similar in size to those employed in the faradic examination, and should be similarly located. The excitability of the nerve supplying the affected muscles should be first ascertained. To do this we first ascertain the strength of current required to stimulate the corresponding healthy nerve if the lesion is unilateral, and compare this with the strength of current required to cause contractions upon the diseased side. Thus, the kathode is placed over the healthy nerve (Fig. 116), and beginning at zero the current is gradually increased in strength, while at the same time it is being interrupted by means of the interrupter in the handle of the electrode, until contractions of the muscles supplied by it are observed. The number of milliamperes or of cells, if a galvanometer is not at hand, required to do this, is then noted and the same process repeated upon the diseased side, when it will be ascertained if there is the same excitability as upon the normal side, or if it is increased, diminished, or absent. If the lesion is bilateral, comparison may be made either with the corresponding nerve of some normal person, remembering that slight differences of excitability occur in the same nerves of different normal individuals, or, if possible, the following table of Stintzing, which gives the limits of milliamperes within which normal contractions should be produced, should be consulted.

Stintzing's Table of Galvanic Excitability of Normal Nerves

Least strength.		Greatest strength.		Average.	
1. N. musculocutaneus	0.05	1. N. musculocutaneus	0.28	1. N. musculocutaneus	0.17
2. N. accessorius	0.1	2. N. accessorius	0.44	2. N. accessorius	0.27
3. N. ulnaris I	0.2	3. N. ulnaris I	0.9	3. N. ulnaris I	0.55
4. N. peroneus	0.2	4. N. peroneus	2.0	4. N. peroneus	1.1
5. N. median	0.3	5. N. median	1.5	5. N. median	0.9
6. N. cruralis	0.4	6. N. cruralis	1.7	6. N. cruralis	1.05
7. N. tibialis	0.4	7. N. tibialis	2.5	7. N. tibialis	1.45
8. N. mentalis	0.5	8. N. mentalis	1.4	8. N. mentalis	0.95
9. N. ulnaris II	0.6	9. N. ulnaris II	2.6	9. N. ulnaris II	1.6
10. R. zygomal	0.8	10. R. zygomal	2.0	10. R. zygomal	1.4
11. R. frontal	0.9	11. R. frontal	2.0	11. R. frontal	1.45
12. N. radial	0.9	12. N. radial	2.7	12. N. radial	1.8
13. N. facial	1.0	13. N. facial	2.5	13. N. facial	1.75

[1] If the coils used in all batteries are of similar length and thickness of wire, the exact amount of coil required to produce contractions of each normal muscle could be ascertained, but as yet no standard coil is used, so that this is impossible; but if the same battery is used continually by the operator he can determine this point for that particular battery, and hence may have a basis of comparison when the lesion is bilateral.

Thus, while in one normal individual, $\frac{1}{2}$ milliampere may excite the musculocutaneous nerve, in another over two may be required, the average for a number of individuals being between one and two.

The muscles are next to be examined, the exciting small electrode (Fig. 113) being placed over the motor point of the muscle being tested (Plates I to VI), and the current being slowly increased and interrupted as described when examining the nerve. The least strength of current necessary to cause contraction when the kathode is over the muscle is first ascertained and the number of milliamperes required noted. The same process is then repeated with the anode over the muscle. It is thus ascertained if either a greater or less strength of current is required to produce KClC than AnClC, or if they are both produced by the same strength of current; in other words, if KClC > AnClC, or AnClC > KClC, or AnClC = KClC. In a similar way the presence or absence of AnOC and KOC and their relation to closure contractions may be determined, these contractions when present occurring when the circuit is opened instead of closed. If a meter is not at hand, the same result can be attained by noticing that a current which will cause KClC will not cause AnClC, or *vice versa,* or that the degree of contraction is the same in either case.

It must also be particularly noted if the contraction is short and quick, or if it is slow, lazy, and tetanic (modal change). This phenomenon may vary in degree according to the severity of the lesion, and in some instances it is only by comparing the contraction with that of a healthy muscle that it can be detected. If the muscles are much degenerated, contraction may only be produced when the voltaic alternative (p. 120) is employed. In such a case the small electrode is placed over the motor point of the muscle as before, then by means of the polarity changer or commutator (Fig. 93), it is made alternately positive and negative.

It should be noticed if the quantity of the contraction when the electrode becomes negative is greater, equal to, or less than that produced when it becomes positive. In other words, if there is serial change. Bérgonie[1] has advised that in extreme cases, when a definite diagnosis and prognosis are required, the nerve be exposed and stimulated. Inexcitability thus found would point to a very grave prognosis.

In addition to the procedures just described, if there is reason to believe that the *myotonic reaction* (p. 156) is present, a strong galvanic current should be passed without interruption longitudinally through the muscles, when the wave-like movements described on page 157 will be produced. Other methods necessary to determine the existence of either the myasthenic (p. 146) or myotonic reactions are mentioned on pages 146 to 156. These are best brought out if the electrodes are placed near the insertion of the muscle.

[1] Archives d'Électricité Médicale, August, 1902.

SOURCES OF ERROR

The principle of current diffusion (p. 109) must be borne in mind when testing for the presence of DeR, for if the neighboring muscles to those diseased are healthy, the diffused current will also stimulate them, and their contractions, being so much stronger, may mask the contractions of the diseased muscles; thus, for example, in the arm the contractions of the flexors, if healthy, might hide, as it were, the more feeble contractions of the diseased extensors. In such cases, if the fingers are laid lightly upon the suspected muscles, contractions may be often felt when they cannot be seen. Owing to this same principle, it is frequently very difficult to isolate the contractions of deep muscles, the overlying ones acting as a mask, and in some cases it is impossible.

Electro-diagnosis Chart

Name ______________________________ Date ______________________

Electrical Diagnosis ____

Treatment ____

Nerve or Muscle	Right						Left					
	Faradic	Galvanic					Faradic	Galvanic				
		CCc	ACc	AOc	COc	Character of contraction.		CCc	ACc	AOc	COc	Character of contraction

If marked serial and modal change should be present, this source of error can be obviated by noticing that the healthy muscles will give the short, quick, minimal KClC, while the diseased muscles will not contract; but these, when the poles are changed, will show the slow, tetanic AnClC, while the healthy muscles will be quiescent. Another source of

error is to suppose that when the healthy muscles contract, the diseased ones do also. Such a mistake could only occur when the healthy and diseased muscles are very close together, and is easily avoided if attention is paid to placing the electrode over the different motor points and noticing if the particular function of the muscle being tested is manifest.

It must also be remembered that in muscles composed of several divisions or segments, as the deltoid or trapezius, DeR may be present in one part and not in another.

It must also be borne in mind that the motor points in some individuals are not in the usual location (p. 163), and the possible occurrence of Doumer's "longitudinal reaction" (p. 171) must be thought of.

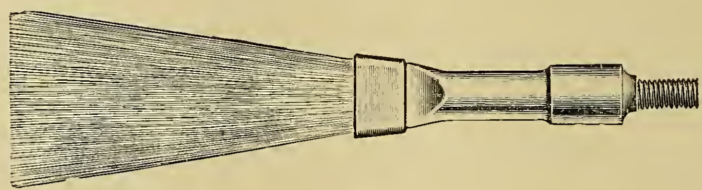
A useful chart for preserving the records of electrodiagnostic examinations is that of Mosher (p. 174).

CHAPTER IX

DISORDERS OF THE SENSORY TRACT, SPECIAL SENSES, AND THE SIGNIFICANCE OF ALTERATIONS OF RESISTANCE

In the examination of the sensory nerves electricity is not of much diagnostic value. It may be used to determine diminution or loss of pain sense. To do so we use a rapid interrupted faradic current, employing, preferably, the dry metallic brush (Figs. 112 and 117) over the area being tested. We have in unilateral diminution or hypalgesia an accurate basis of comparison by noticing the different amounts of separation the coils (p. 158) require on each side to cause painful sensations. Thus, the patient being blindfolded, the dry brush is placed over the analgesic area and the secondary coil gradually slid over the primary until painful sensations are felt; this distance should

Fig. 117



Brush electrode.

be noted; then the electrode is placed over a corresponding area in the healthy side and the process repeated. Of course, the diseased side will require more coil than the normal. Erb has constructed a table of normal faradic sensibility which may prove useful as a basis of comparison when the sensory paralysis is bilateral. It is only of value when a standard coil is employed.

Place of examination.	First sensation with a separation of coils of	Marked pain perception with separation of coils of
Cheek	200 to 220 mm.	120 mm.
Neck	180 to 200 "	120 "
Arm	200 "	120 "
Forearm	190 "	115 "
Dorsum of hand	175 "	110 "
Points of fingers	125 "	90 "
Abdomen	190 "	120 "
Leg	170 "	110 "
Dorsum of foot	175	11[illegible] "
Sole of foot	110 "	80 "

In tabes dorsalis there is sometimes found a faradic analgesia without impairment of other forms of sensation. Disease of the vertebra may be detected and located by passing the kathode of the galvanic current, which should be strong, along the spine. When a diseased vertebra is reached, severe pain is caused (Rosenthal's sign). The use of the faradic brush may be of service in detecting simulated analgesia.

Hyperesthesia can, of course, be similarly detected. In such a case sensation will be felt with a less separation of coil than is required when normal sensibility exists. This may be utilized in the diagnosis of tetany, in which, if a sensory or mixed nerve is excited by a weak current, paresthesia is caused in the area supplied by the nerve (Hoffman's symptom, p. 144). Frankl-Hochwart and Chvostek have reported cases of increased irritability of the auditory nerves. Attempts have been made to utilize the physiological action of the galvanic current upon the special sense nerves (p. 126) in the diagnosis of their disorders. So far, except for the auditory nerves, it has not proved of much practical value.

Loss of *sense of taste* may be determined by the use of an electrode consisting of a fine wire point and a galvanic current of from $\frac{1}{10}$ to $\frac{1}{2}$ milliampere in strength. The electrode is placed on the tongue, when, if normal, taste perception is caused. Different small areas of the tongue can be tested in this manner. For this purpose may be employed the electrode of Neumann, which consists of two wires insulated from each other, but bound together to a short distance from their ends, which consist of little balls. They are connected respectively to the poles of the battery. While the different poles of the galvanic current produce, when applied to the eye, different colors according as the circuit is opened or closed, and different sounds are likewise caused when applied to the ear (p. 126), no definite relationship of these phenomena to disease has as yet been determined. When the current is applied to the eye the electrode should be placed on the lid of the closed eye and a current of not more than 1 milliampere used.

In the case of the auditory nerves practical information may be obtained by noticing differences from the normal phenomena detailed on page 126. Thus, if the nerve on one side is diseased, less anodal amperes will be required to cause nystagmus than kathodal. As has been said (p. 127), electrical tests apply to the nerve only, hence it is also necessary to determine the condition of labyrinth or end organ by either the caloric or turning tests (for which see treatises on diseases of the ear). If there is no reaction to these, but a normal reaction to the electric test, it is safe to say that the nerve is not diseased but the labyrinth is. If there is no response to any of the three tests, then we can diagnosticate a lesion of the nerve or its centre (Neumann).

In cases of the hypersensibility found sometimes in hysterical and neurasthenic patients, it will be found that less kathodal amperes than anodal are required to produce nystagmus, also that less kathodal amperes than normal will produce it, while more anodal than normal will

be required. The following directions for making these tests are condensed from those given by Mackenzie (*loc. cit.*) Care must be taken to have an accurate meter, a large, flat electrode, and a small one (1 cm.) with interrupting handle (Figs. 113, 114, and 115), and a switch to change the polarity (Fig. 93). An assistant is needed to control the switches and watch the meter. Good illumination from a head mirror worn by the observer. In using this it is necessary to have a light placed behind the patient's head. Care must be taken not to reflect the light too strongly into the eyes. The operator should stand facing the patient, slightly to the left when examining the left side, and to the right when examining the right. The patient should look straight ahead at some distant point over the observer's shoulder, and his head should be inclined slightly backward. It should first be noted if spontaneous nystagmus is present or not, and if so, its character. The upper eyelid should be slightly elevated by the thumb of the observer, so that the sclera above the cornea is exposed, care being taken not to touch the eyeball or lid edges.

The electrodes must be kept thoroughly wet with warm salt water. The large electrode is placed at an indifferent point, equidistant from each ear, and kept at the same place during the examination; one that can be fastened (Fig. 111) will prove useful.[1] The small electrode is placed in front of the tragus. The current is gradually increased until nystagmus is noticed, when is determined its direction and the number of milliamperes, and pole used. Each ear is thus tested with both anode and kathode.

Cocaine cataphoresis (p. 114) may be of use in differentiating superficial pain from that due to lesions far back of the point to which the electrode is applied, as in disease of the Gasserian ganglion, or the idiopathic neuralgias of central origin (Starr). Pain of superficial origin being relieved by the method, while that due to the latter causes is not. It also may be of service in differentiating real from hysterical pain. Thus, Peterson[2] mentions a case in which he was enabled to make a diagnosis of hysterical knee-joint because, when the patient's eyes were closed and cocaine cataphoresis applied to the intensely hyperesthetic skin, after a few minutes a pin could be stuck into the spot without its being felt; but when her eyes were opened, touching this anesthetic spot was painful as before.

Alterations in the resistance of the body to the passage of the current have been found in some pathological conditions, notably exophthalmic goitre, in which the initial resistance is reduced, also in hysterical anesthesia (Vigouroux) and in the traumatic neuroses (Mann). It has been claimed that it is increased in the paralyzed side in the cerebral palsies of childhood (Vigouroux and Mann), in scleroderma, myxedema,

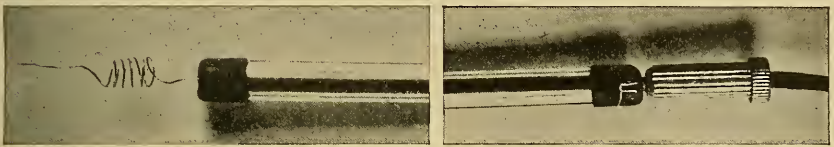
[1] Mackenzie places this electrode in the patient's right hand and keeps it there, stating that he has never seen it make any difference in the tests.

[2] International System of Electrotherapeutics, second edition, p. B. 343.

and elephantiasis. The practical utility of these observations is small. Methods for determining this have been described on page 108.

If it is desired to *extirpate a cortical motor centre,* which to the naked eye is not diseased, as is sometimes the case in operating for epilepsy, the faradic current is used to identify the centre. In cases where the topography is not clear it may also have to be used to *identify the central fissure* (of Rolando). Cushing employs a long glass unipolar electrode carrying a fine platinum wire coiled into a spiral at the end

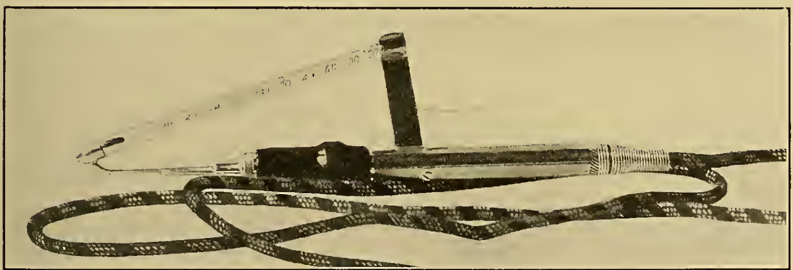
Fig. 118



Showing terminal and connection of Cushing's electrode (¾ natural size) Instrument should be sixteen inches or more in length. (Keen.)

(Fig. 118). The indifferent or dispersing electrode is applied to the leg of the same side. The current should be just strong enough to contract exposed muscle. Some of the temporal fibers may be used for the test. If there is an abundance of cerebrospinal fluid in the arachnoid spaces, it must be evacuated by pricking the membrane where it crosses the sulci. The patient should not be too deeply anesthetized. Of course, the electrode must be aseptic.

Fig. 119



Profs. E. B. Twitmyer and C. K. Mills, of the University of Pennsylvania, have devised a convenient instrument (Fig. 119) for use when great accuracy is desired in the *examination of temperature sense.* It depends upon the power of the galvanic current to generate heat, which, of course, becomes greater or less as the current from the battery is made stronger or weaker. The amount is measured by the thermometer seen in Fig. 119.

The development of electric currents by contracting muscle (p. 106) has been utilized recently as an aid in the study and diagnosis of faulty

cardiac action.[1] By means of the very sensitive galvanometer devised by Prof. Einthoven, tracings are made which differ in certain diseased conditions from that obtained in a healthy person.

Fig. 120

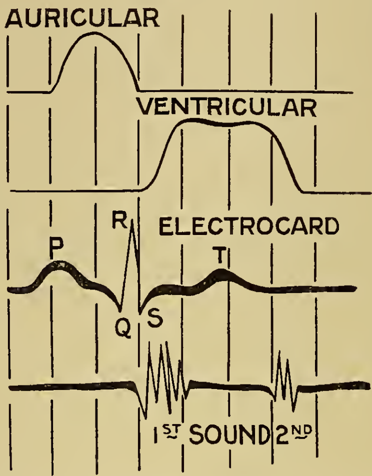
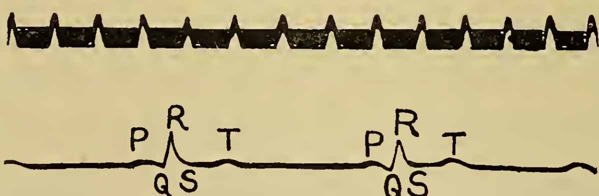


Diagram showing the time relations between the waves of the electrocardiograms, the heart sounds, and the contractions of auricles and ventricles. The short interval between the beginning of the R wave and the beginning of the rise in the intraventricular pressure is interpreted by Kahn as due to the phenomena of conduction within the heart. In experimental ventricular extra-systoles the electric and mechanical changes are absolutely synchronous. Vertical divisions indicate tenths of a second. (Barker, Hirschfelder, and Bond.)

Figs. 120 and 121 show normal tracings. The first wave, *P*, is due to activity of the auricle, the large wave *R* is due to the contraction

Fig. 121



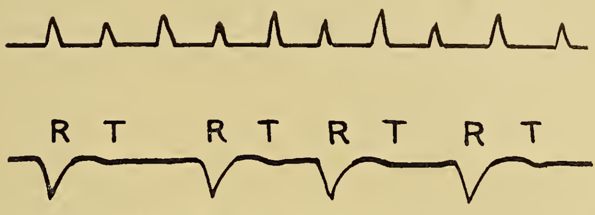
Typical electrocardiogram from a normal man. Current led off from right hand and left foot (*D* 2). Upper line, times marking fifths of seconds. (Barker, Hirschfelder, and Bond.)

of the ventricles, followed by the depression *S*, which in turn is followed by a small second wave, *T*, occurring during the middle of the systole.

[1] James and Williams, The Electrocardiogram in Clinical Medicine, American Journal of Medical Sciences, September, 1910, p. 408. Barker and Hirschfelder, The Electrocardiogram in Clinical Diagnosis, Journal of the American Medical Association, October 15, 1910, p. 1350.

Fig. 122 shows that of a case of hypertrophy of the left ventricle, and Fig. 123 one from a case of heart-block. They seem to be of special value in the study of cardiac arrhythmia. Space will not permit a

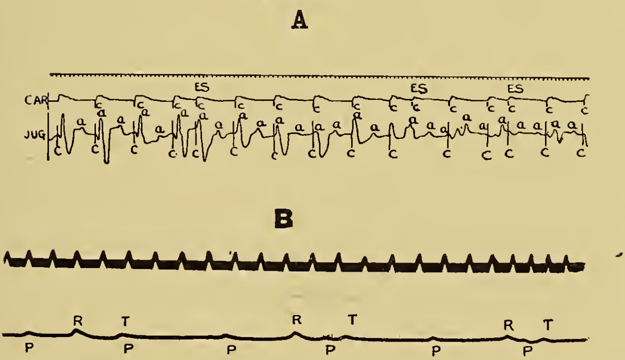
Fig. 122



Upper line, timer, marking fifths of seconds; lower line, electrocardiogram. Inversion of the *R* and *T* waves due to hypertrophy of the left ventricle. Current led off from left hand and left foot (*D* 3). The *P* wave, due to the atrial activity, is absent. (Barker, Hirschfelder, and Bond.)

complete description of the technique and uses of this method. The reader is referred to the papers cited. Tracings of the heart sounds may also be made by utilizing the principle of the telephone. A stethoscope is placed on the patient's chest and the heart sounds are led to

Fig. 123



A, venous and carotid arterial pulse from a patient with complete heart-block and pulse rate of 33 per minute; *B*, electrocardiogram from the same patient. Upper line, timer in fifths of seconds; lower line, electrocardiogram. The rate of the atria is about twice that of the ventricles, but the complete dissociation between the two is more readily discernible in the electrocardiogram than in the venous tracing. (Barker, Hirschfelder, and Bond.)

the microphone through a rubber tube. The sound waves cause telephone currents, which are carried to the galvanometer and cause the string to vibrate. The vibrations are traced on a revolving drum.[1]

[1] Barker and Hirschfelder, Journal American Medical Association, October 15, 1910, p. 1352.

CHAPTER X

ELECTRICITY AS AN AID IN PROGNOSIS

In lesions of the peripheral neuron (Fig. 94) the character of the electric reaction may be of much service in formulating a prognosis. As Erb puts it, "Other things being equal, the lesion is serious, the probable duration of the disease longer, and the definite prospect of a cure more remote in proportion as the DeR is developed and complete, and in proportion to the stage which it has reached."

In rheumatic neuritis of the facial nerve this has been so worked out that from the character of the reaction we can predict not only the prospect of recovery, but the length of time that will be required. Thus, cases in which, say, at the end of the second week, either the reactions are still normal or only a quantitative decrease is present, the probable duration of the trouble can be placed at three weeks. If a partial DeR is found, the case will probably last one or two months. If a complete DeR is present the duration will be from three months to a year, and possibly may be incurable. These rules do not apply to inflammation of the seventh nerve produced by middle-ear disease; in such a case recovery will not begin until the ear trouble is remedied.

In any case of peripheral nerve trouble, even where the most marked DeR is found, hope of improvement should not be given up until treatment has been persisted in for a year or more. If a return of excitability in a muscle or nerve in which it has been absent is discovered at any time during this period, it is a good prognostic omen. If the tardy muscular contraction becomes more quick, even if the galvanomuscular excitability is very slight, the outlook becomes favorable; but if the tardiness becomes more pronounced after a period of several months or more, the opposite is the case.

Sometimes when the DeR is marked the power of voluntary contraction of the muscle may return before the contraction to electrical stimulation does. This, of course, is of favorable significance. In progressive diseases, such as progressive spinal muscular atrophy, changes in the electrical reactions may precede the loss of voluntary power. In such cases diminution of electrical excitability in a muscle foretells that sooner or later loss of voluntary power will occur in it.

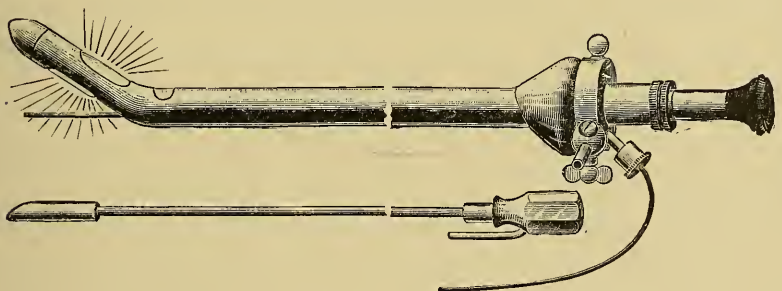
In cases where it is necessary to decide if a nerve trunk is divided or only bruised, inflamed, or pressed upon by scar tissue or callus, the character of the DeR may be of much diagnostic and consequently also prognostic significance. Thus, if in a suspected case, after several weeks, merely a partial DeR was found in one or all of the muscles

supplied by the affected nerve, it would be safe to say that it was not divided; at the same time it must not be forgotten that complete DeR might be present in a case where division had not taken place and other symptoms must then be taken into consideration. After a divided nerve has been sutured the reappearance of electrical excitability and the improvement in the character of the DeR are valuable aids in determining that the operation has been a success. In cases of secondary suture it may be months before such occurs, and in all cases it is well to remember that improvement in sensation occurs first.

THE ELECTRIC LIGHT AS AN AID TO DIAGNOSIS

The endeavor to illuminate the cavities of the body for diagnostic purposes had its origin in 1805, when Bozzoni[1] conceived the possibility of throwing light into the bladder. Other instruments for this and similar purposes were afterward devised, but none were very efficient until the incandescent electric light was employed. The various instruments which have been devised for these purposes will be mentioned, but for indications for their use and the technique of their application the reader is referred to the treatises devoted to the diseases of the part mentioned. The source of the electricity to illuminate the lamps may be obtained either from an electric light circuit or a cell or storage battery.

Fig. 124



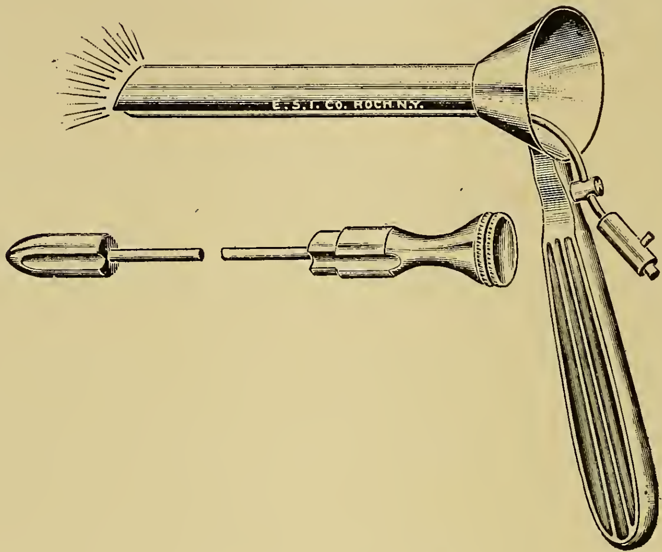
Belfield's ureter catheterization and diagnostic male cystoscope.

Cystoscope.—The cystoscope is a valuable aid in determining the nature of obscure affections of the bladder. It may also aid us in some affections of the kidneys, as by its use we may either determine the appearance of the stream of urine from each kidney, or by catheterizing the ureters collect the urine from each kidney for examination. Various forms of the instrument have been devised; one is shown in Fig. 124,

[1] Transactions American Electrotherapeutic Association, 1894, p. 295.

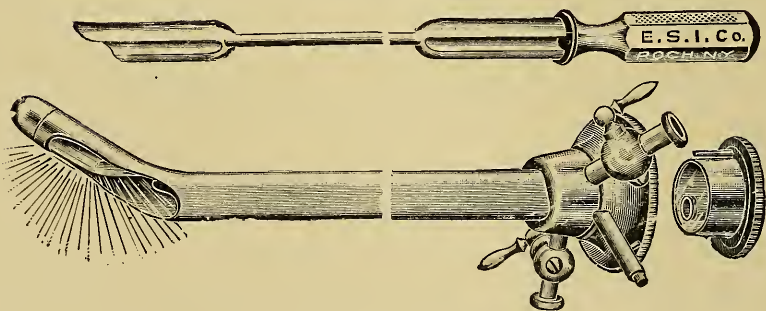
others in Figs. 125 and 126. A *catheterizing cystoscope* is shown in Fig. 124. An instrument to be used in operations upon the bladder is shown in Fig. 126.

Fig. 125



Howard A Kelly's female cystoscope.

Fig. 126

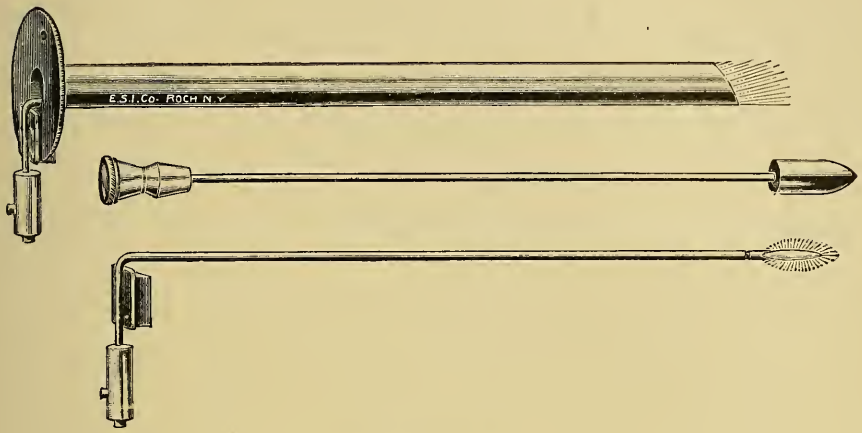


Bransford Lewis' operating cystoscope.

Endoscope.—The endoscope or urethroscope is employed to obtain a visual examination of the mucous membrane of the urethra, and may also be used in the treatment of localized areas of inflammation, erosions, infiltration, and inflammation about the urethral follicles, granular patches, papillomata, and polypi. Such treatment can only be carried out by the aid of this instrument, the lesion being first exposed by it

and then the desired drug being applied by means of a suitable applicator. An example is shown in Fig. 127. That of Fenwick is arranged

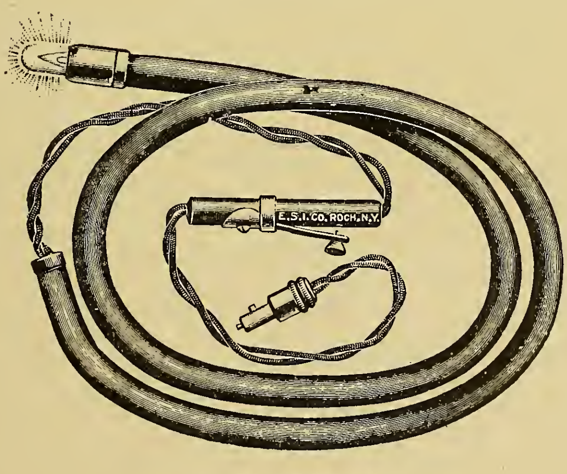
Fig. 127



Valentine's urethroscope.

so that after the tube is introduced the urethra can be inflated with air, thus exposing a long, flat wall instead of a small circle of relaxed mucous membrane, as seen with other instruments. While the best

Fig. 128

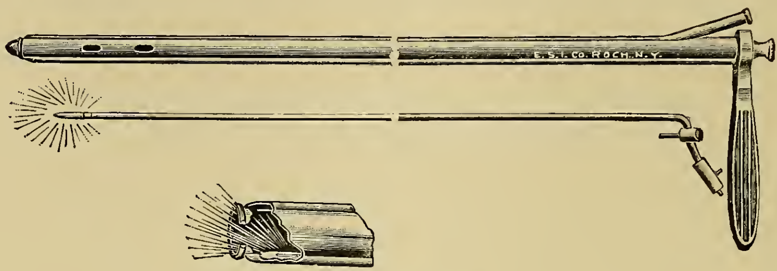


Einhorn's gastrodiaphane.

source of light is a small lamp inside the tube (Fig. 127), the reflected light from a head mirror can be used (Fig. 138).

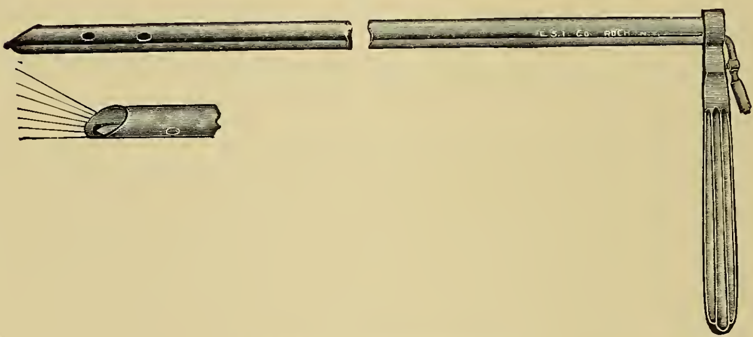
Gastrodiaphane.—The gastrodiaphane (Fig. 128) was devised by Einhorn to illuminate the stomach and thus enable one to determine

Fig. 129



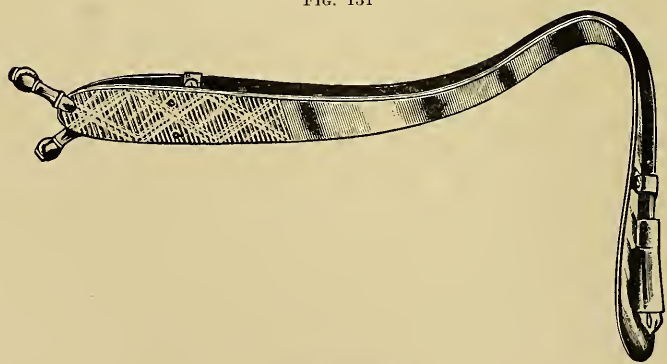
Jackson's bronchoscope.

Fig. 130



Jackson's bronchoscope, slanted end.

Fig. 131



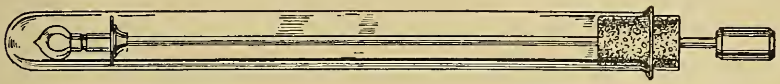
Tongue depressor.

its outlines by observing the illuminated area through the abdominal walls. S. Solis Cohen[1] has achieved better results by employing fluores-

[1] American Medicine, July 16, 1904, p. 118.

cent solutions in connection with the light. He claims that by so doing the area of illumination is increased and the degree of manipulation of

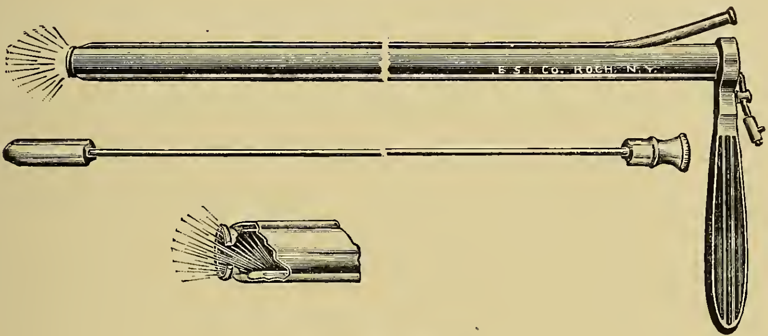
Fig. 132



Lamp for abdominal operations.

the light diminished. The patient is given quinine bisulphate, gr. ij t. i. d., previous to the examination, and about a minute before the lamp

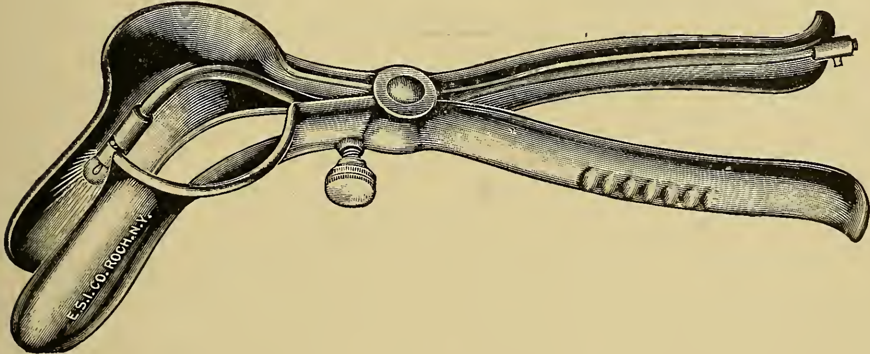
Fig. 133



Jackson's esophagoscope.

is introduced he should drink a tumblerful each of solutions No. 1 and No. 2. No. 1 consists of $2\frac{1}{2}$ grains of bicarbonate of soda to the ounce

Fig. 134

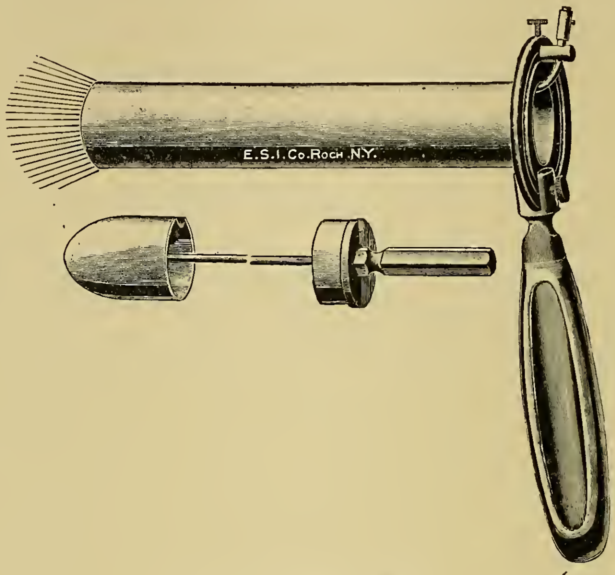


Pratt's rectal speculum.

of distilled water; No. 2, of glycerin, fʒij, and fluorescin, gr. $\frac{1}{4}$, to the pint of some basic alkalinized water. The gastrodiaphane is especially

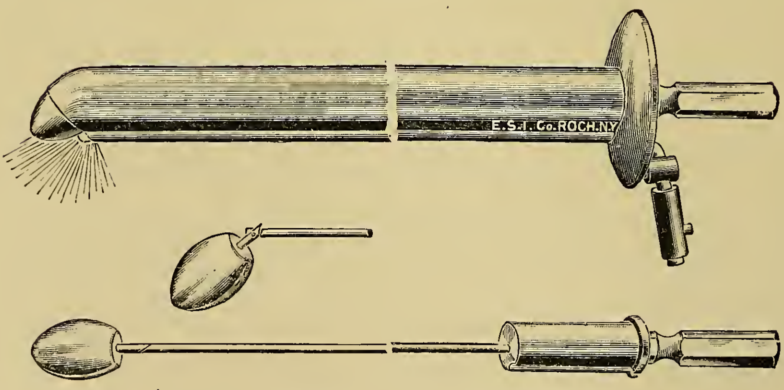
useful in determining the position of the lesser curvature and in discriminating between gastric and hepatic tumors. Chevalier Jackson has devised an instrument for inspecting the esophagus (Fig. 133).

Fig. 135



Tuttle's operating proctoscope.

Fig. 136



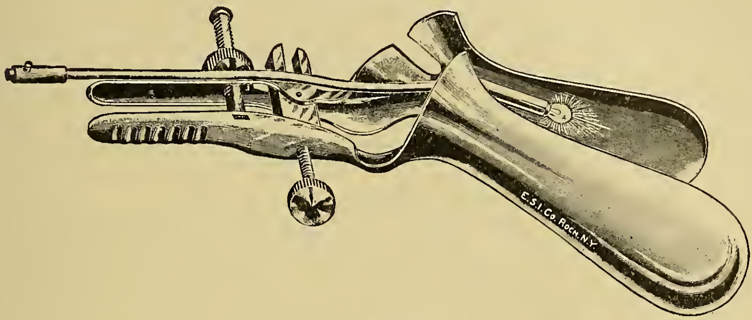
Tuttle's sigmoidoscope with Mercier curve.

He[1] also has devised instruments by which the bronchi may be illuminated and foreign bodies lodged there discovered and removed (Figs. 129 and 130). Tongue depressors are shown in Fig. 131, and a

[1] Journal American Medical Association, September 25, 1909, p. 1009.

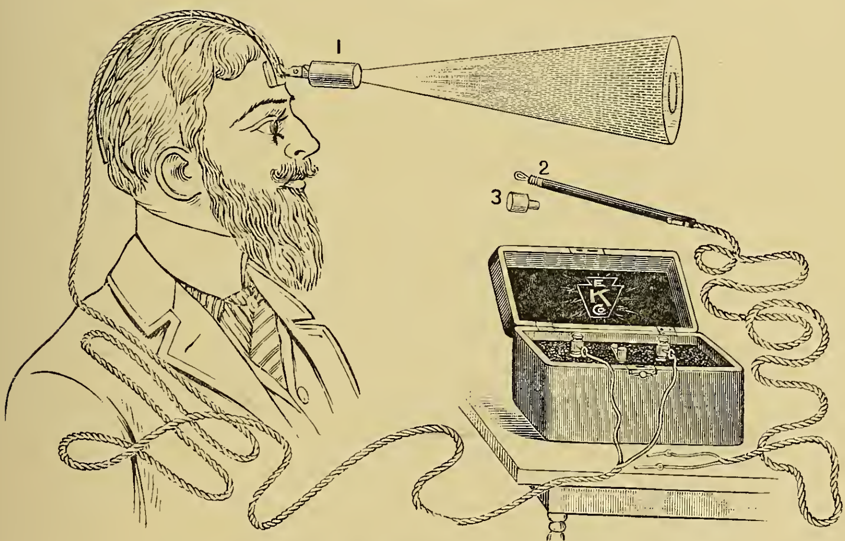
lamp for use in abdominal operations in Fig. 132. It is introduced through wounds during abdominal operations, to find bleeding arteries,

Fig. 137



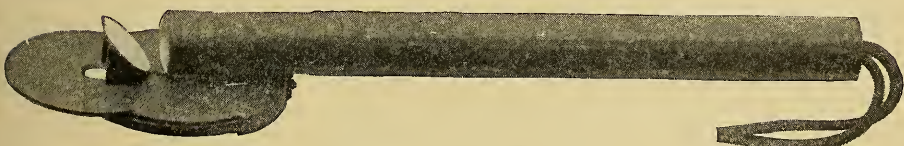
Vaginal speculum.

Fig. 138



Keystone portable lamp outfit.

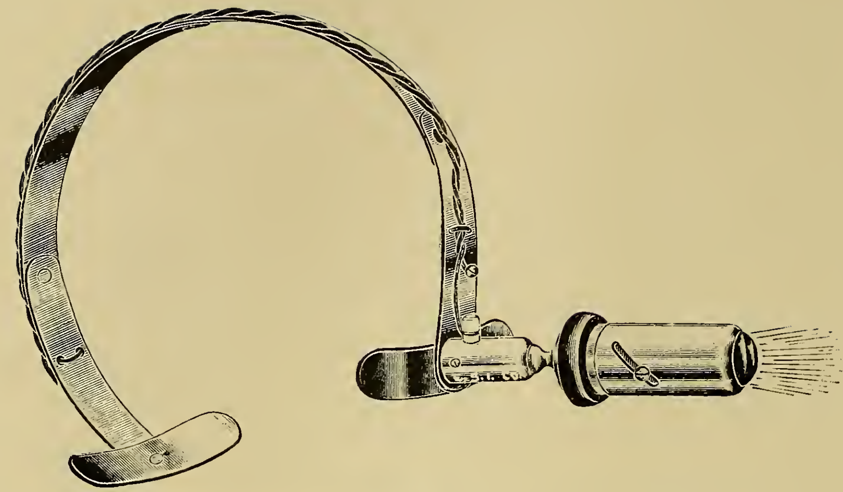
Fig. 139



De Zeng ophthalmoscope.

etc. The lamp is protected, so as not to dazzle the eye of the operator. The instrument can easily be cleaned in carbolic acid.

Fig. 140

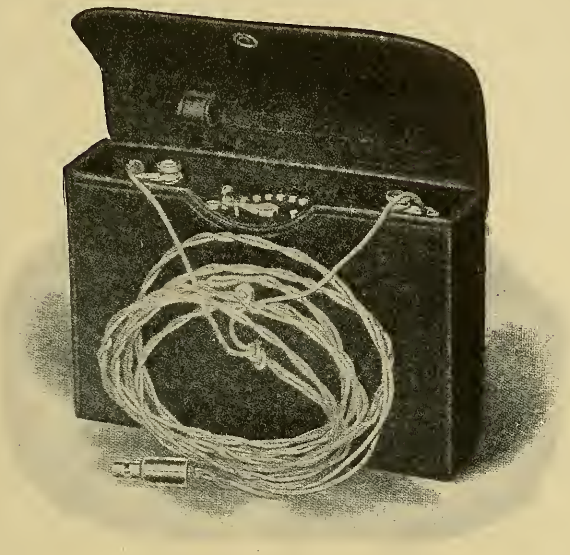


Head lamp.

Fig. 141

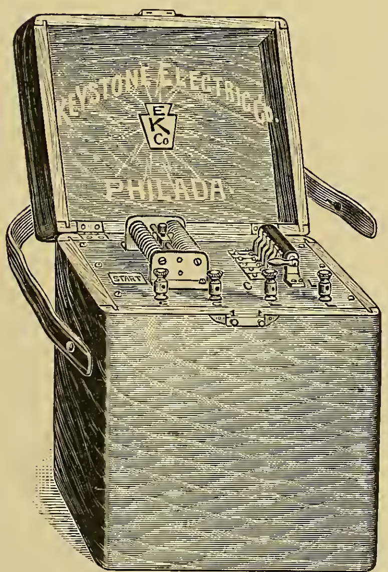
General diagnostic outfit, with rectal tube, comprising the following instruments: 1 illuminating battery, style A, with cord; 1 auriscope, style A or B, with three specula; 1 laryngoscope; 1 tongue depressor; 1 general diagnostic illuminator; 2 Koch urethroscopes (any sizes); 1 light carrier for urethroscopes (interchangeable); 1 E. S. I. Co. rectal tube (any size); 1 light carrier for rectal tube.

FIG. 142



Pocket battery.

FIG. 143



Keystone dry cell cautery and diagnostic lamp battery No. 1.

Various Instruments.—Instruments for exploring the nose, throat, ear, and accessory cavities are shown on pages 341 and 344. The light attached to a *rectal speculum* is shown in Fig. 134. Another form to be used while operating is shown in Fig. 135. The sigmoid can also be illuminated by means of Fig. 136. A *vaginal speculum* is shown in Fig. 137.

Small electric lamps are very convenient for testing the *pupillary light reflex.* Such an instrument is shown in 2 in Fig. 138, and ophthalmoscopes with electric light attachment (Fig. 139) are very useful. *Surgical operations* in localities where an intense illumination is desired may be much facilitated by the use of some form of head light such as shown in Figs. 138 and 140. A convenient set of instruments is shown in Fig. 141, which includes the battery. This one may be either a dry cell battery, as shown in Figs. 142 and 143, or an electric light circuit, when a wall plate, as Fig. 104, may be used.

SECTION IV

GENERAL ELECTROTHERAPEUTICS

Study of the section on Electrophysiology will show that the electric current has both exciting or stimulating and sedative or inhibiting powers (electrotonic effects), also that it acts by producing electrolytic and phoretic action and influencing nutrition and circulation. In addition, however, it is important to remember that in certain classes of cases at least, a large part of its power for good depends not upon the production of these material effects, so to speak, but upon its psychic influence; in other words, its power of producing mental impression and suggestion. To a certain extent these material and psychic effects may act in combination, as in the hysterical when the current properly applied may both improve the nutrition of the patient and also act as a powerful suggestive agent.

All the forms of current do not possess these powers in the same degree; it is therefore necessary to remember which current is best suited for the obtaining of certain effects and also the ways and means of applying the current to best obtain them. The galvanic or constant current is the most generally useful if only one form of current can be obtained. The induced current will probably come next. These general rules and methods of application constitute general electrotherapeutics. Their application to special organs and branches of medicine are considered as special electrotherapeutics.

CHAPTER XI

GENERAL RULES AND PRECAUTIONS

APPARATUS REQUIRED

From what has been said above (see also pp. 158 to 162), it will be seen that for the more usual applications of electricity in medicine, such as the general practitioner should be called upon to apply, the necessary appliances are a constant source of current; some means of controlling the current so that it can be either increased or decreased in strength gradually (Fig. 105); a current reverser (Fig. 93); if possible a milliampere meter (Fig. 44); an induction apparatus (Figs. 106 and 109), with means of obtaining both slow and rapid interruptions; conducting cords (Fig. 144); large and small electrodes (Figs. 110, 113, 114, and 115), and a wire brush (Figs. 112 and 117).

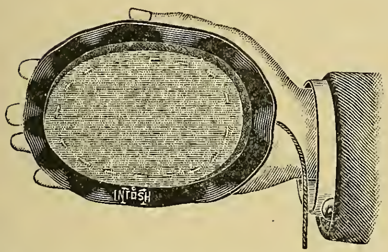
When very strong currents are being used, as is necessary at times in the treatment of some gynecological conditions, special forms of indifferent or dispersing electrodes must be used. One of the best of these is the Apostoli clay pad (Fig. 148). This should be made of potter's clay, kept in the consistence of soft mud by admixture of water in a covered crock. It should be freshly made for each application, and is most comfortable for the patient when heated in a jacketed pan (Fig. 149), in the space between the double bottom and sides of which boiling water has been poured. Before putting the clay in the pan, two layers of mosquito netting or a single layer of tarlatan should be placed in the bottom, and should be large enough to project over the sides of the pan, so that the clay can be lifted out. The clay is then spread over the netting to the thickness of an inch and large enough to cover the abdomen. After it is placed on the patient, a block tin or lead plate with a binding post (Fig. 148, *b*), for attachment of the cord from the source of electricity, is pressed down upon it. Another form of clay pad is described on page 396.

Excellent pads which can be placed anywhere on the body are the Massey wired-cotton pads (Fig. 150). These are made as follows: "In the centre of a piece of muslin, somewhat larger than the intended pad, the end of a spool of No. 20 soft brass wire is seen. The wire is then coiled in an increasing spiral and securely sewed in place in the muslin, each spiral being about half an inch from the preceding one, until the desired size is obtained, the shape being oval for the large pad and round for the smaller. When it has attained dimensions of about 7 x 11 inches for the larger and 6 inches for the smaller, a

Fig. 144

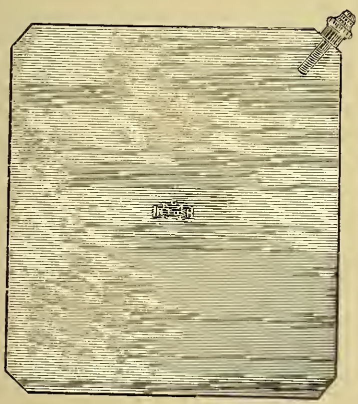
Covered conducting cords for electrodes.

Fig. 145



Sponge-covered electrode, insulated with soft rubber for general application with the hand.

Fig. 146

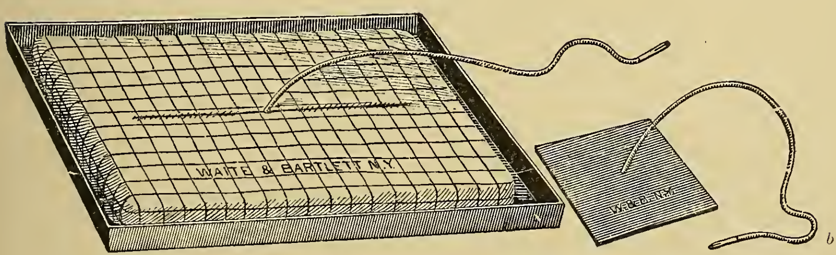


Metallic foot plate.

Fig. 147

Round sponge electrode with long insulated handle.

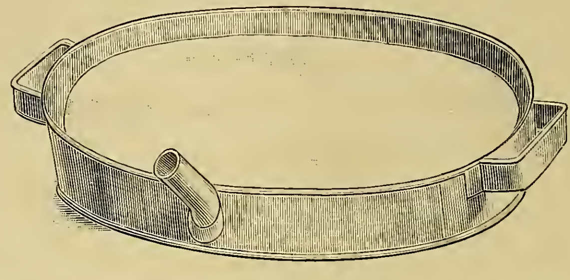
Fig. 148



Apostoli's abdominal clay electrodes.

small turn is made in the wire and sewed down to prevent pulling out, and a considerable length of wire is left for connection with the battery. This free end should be at one end of the spiral for the large pad and in the centre of the small one. Six or eight layers of absorbent cotton

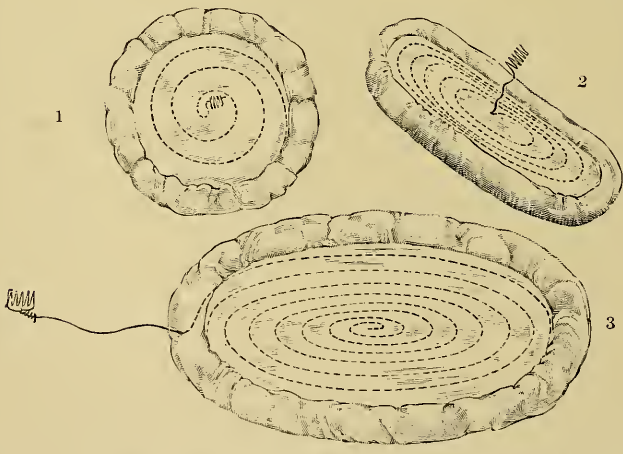
Fig. 149



Jacketed pan for clay pads; hot water is poured into the interior through the pipe shown. (Massey.)

should now be placed on the wire side, and on top of the cotton a piece of muslin is placed to be folded over and sewed to the edge of the back of the pad. The pad should now be quilted lightly through and through to keep the cotton from packing, and when the end of the wire left free is made into a spiral friction socket, for connection

Fig. 150

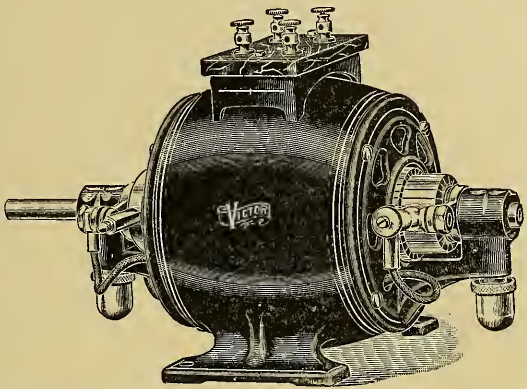


Massey wired-cotton electrode pads: 1, abdominal pad for general use; 2, spinal pad; 3, large dispersing pad.

with a battery tip, by winding it about the end of the tip, the electrode is complete." Various other styles of large pad electrodes have been devised, examples of which are shown in Figs. 110, 145, and 146. When strong currents are used they should be covered with soap and water.

If it is desired to employ the agent more extensively, in order of their value may be mentioned a good static machine. Means of obtaining the sinusoidal (Fig. 151) and high frequency currents, the static machine can be utilized for obtaining the latter (p. 36 and Fig. 160) and various special electrodes (pp. 229 and 235).

Fig. 151



Motor generator converting the direct to an alternating current; a sinusoidal wave current is produced.

When using street currents it may be necessary at times, when a new socket is first used, to ascertain its polarity; this may be done as described on page 389. Also, if the available current is of the alternating type, a rectifier (p. 87) must be used.

RULES TO BE OBSERVED IN THE APPLICATION OF GALVANIC, FARADIC, AND SINUSOIDAL CURRENTS

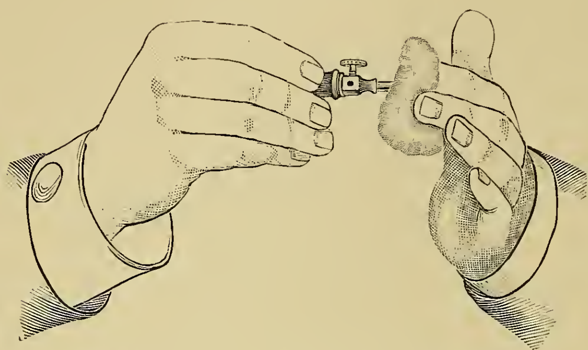
Observation of the following rules is most important:

It is necessary to cover the electrode for two reasons, first, the bare metal, owing to its electrolytic effect, would, in the case of the constant current especially, be excessively painful and irritating; second, as the dry skin is a poor conductor, it is necessary that it be moist for the current to affect the tissues beneath, therefore the electrode must be covered with something which will hold moisture.

For this purpose a covering consisting of a thick layer of absorbent cotton dipped in either warm water or a solution of common salt is preferable. If accurate contact with the skin is desired, it may be soaped in addition. Electrodes are frequently covered with sponge; this, however, soon becomes filthy and should not be used. The cotton can and should be changed for each patient. Figs. 152 and 153 illustrate how to place it on the electrode. Before beginning the application one should make sure that the current is turned off. If this is not done a painful shock might possibly be given the patient.

It is of the utmost importance that the patient be not caused pain, particularly in the early applications, until his confidence is secured. Patients, especially nervous women, are frequently afraid of electricity, and a painful shock might alarm them so that they would lose confi-

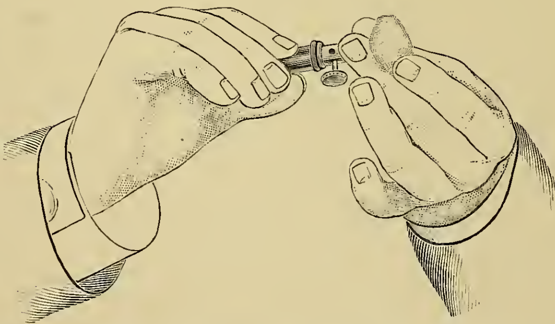
Fig. 152



Applying absorbent cotton to electrode disk, first stage. (Massey.)

dence, and further treatment could not be carried out. As a matter of fact, it is rarely necessary to cause it. Do not, unless necessary, place the electrodes over bones which are thinly covered with soft tissues, as the tibia, as considerable pain is produced by so doing. Strong currents, if interrupted, should never be employed about the head or face.

Fig. 153



Applying absorbent cotton to electrode disk, second stage. The cotton is fixed in place by being well twisted about the shank. (Massey.)

Vertigo is sometimes caused by applications to this region. In this locality especially treatment should be begun with exceedingly mild currents, which may be increased in subsequent treatments as tolerance is established.

To insure the non-causation of pain, it is a good plan to ascertain first that the apparatus is working properly. This is best done by testing it upon one's self.

The application should be begun with the weakest obtainable current, which is gradually increased until the desired effect is obtained.

In the case of children or very nervous and timid people, the electrodes may first be placed in position and allowed to remain for a few moments without the current being turned on. It may then be gradually increased as above stated. In some cases of such nature it may be well not to employ the full strength of current necessary until after several applications have been made.

When the application is to be discontinued the current should gradually be diminished in strength to zero. It must be remembered that too strong and too long-continued applications may do harm (see page 206). If muscular contractions are desired, the current should only be of sufficient strength to produce a visible contraction, and about a dozen contractions of each muscle treated are sufficient. In some forms of paralysis (page 300), it may be well not to endeavor to cause contractions at all. Without there is some indication to the contrary, three applications a week are all that is necessary. In some cases less than this may be sufficient. In general applications, as general faradization, for instance, the application may be continued longer and treatment given oftener. When, however, the constant current is employed without break, the application may be longer continued and more frequently applied. If a meter is not at hand, a feeling of comfortable warmth is a fair guide to the proper strength. When a meter is in the circuit the dose is regulated by the number of milliamperes required, the proper number of which will be stated under the special conditions requiring such treatment (Section VI).

The operator should always sit so that the means of regulating the current strength is within easy reach.

The fact that the resistance of the skin becomes less, and hence the current strength stronger, during the passage of the current should be remembered (page 107).

Electrical treatment, as a rule, is contraindicated in those with fever, who are much debilitated (as from cancer and tuberculosis), very old people, and in menstruating or pregnant women. Further precautions to be observed in using other forms of current are given on pages 211, 212, and 219.

After the treatment is finished all switches must be turned off and the apparatus for regulating current strength be placed at zero.

Sometimes no current can be obtained from a battery. One reason why this may occur is the rusting or corroding of metal surfaces with which the switches come in contact. These should always be kept bright and clean. This also applies to the plates of metallic electrodes.

Another reason may be a break in one of the conducting cords. This

can be located by holding the electrode attached to one cord in one hand, while the moistened fingers of the other hand touch the binding post to which the other cord is attached. The current is then turned on; if it is felt, we know that the cord used is intact. The other cord is then tested in the same manner, and if no current is felt we know that this cord is not intact. If a current should not be felt in either case, we know that the trouble is either due to wearing out of the cells or a break in some of the connections of the switch board.

In using the slow interrupter of the faradic battery we must be sure that the arm of the lever can rise a little above the magnet, otherwise no pull can be exerted and it remains stationary. It is equally important, when the rapid interrupter is used, that the screw *N* in (Fig. 66) comes close to but not in contact with the metal bar. It may be necessary to give this a light blow in order to start it. Bringing the electrodes into contact while the current is turned on must be avoided, as by so doing the battery is short circuited and damage may result. Non-attention to these precautions may be a cause of no current. As the proper application of electricity is based on physiological knowledge and experience, the patient should never be encouraged to treat himself.

CHOICE OF POLE TO BE USED AND DIRECTION OF THE CURRENT

Owing to the alternating character of the faradic current there need, as a rule, be no choice of poles when it is employed, as there is no marked polar action. Owing, however, to the reasons detailed on page 89, the current produced on opening is so much stronger than that produced on closing, that the latter is often not considered, in which event the faradic current will consist of a momentary current which flows in one direction, hence there will be a constant anode and kathode. In such a case muscles usually react better to the kathode (p. 74).

When the galvanic current is employed, the selection of the proper pole is of some importance. This is based upon the respective productions of katelectrotonus and anelectrotonus by the kathode and anode (p. 115), hence when we wish to produce increased excitation or stimulation, as would be the case in treating motor or sensory paralysis we make the exciting electrode the kathode; if, on the other hand, sedative or quieting effects are desired, as would be the case in the treatment of pain or local spasm, the anode is made the active electrode. In either case, whenever we wish to secure the polar influence the other electrode should be placed at some distance from the part being treated.

As the current will not flow in one direction through the body (p. 111), the direction of the current is of no importance. When the anode is central and the kathode peripheral we term the current a

descending one. If the position of the poles is the opposite to that just mentioned, it is termed an ascending one.

The sinusoidal being a true alternating current (page 77), the pole used need not be considered.

PLACE OF APPLICATION AND SIZE OF THE ELECTRODES

If we wish to act directly upon a diseased part the electrodes should be placed as near as possible to the seat of the disease; thus, if we are treating a paralyzed muscle, the active electrode should be placed over the motor point of that muscle, while the indifferent electrode may be placed as near as possible to the nerve trunk supplying it (Fig. 154); if painful conditions of a nerve are being treated, the electrode should

Fig. 154

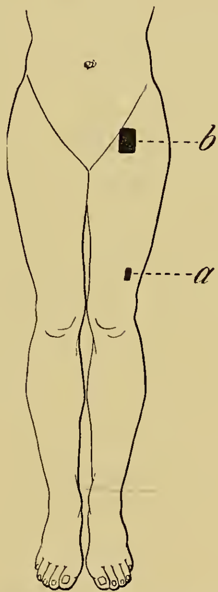


Diagram showing position of electrodes for causing contraction of a muscle. The active electrode should be negative: *a*, active small electrode over motor point of vastus externus muscle; *b*, indifferent large electrode over anterior crural nerve.

be placed as nearly as possible to where the nerve trunk is nearest the surface (Plates I to VI). Jacoby[1] speaks of an indirect method to be used when it is not possible directly to influence the diseased part. This method is based upon the observations of Head[2] in reference to the relationship of the viscera to the nerve supply of definite cutaneous

[1] Electrotherapy, vol. ii, p. 136.

[2] On Disturbances of Sensation, with Special Reference to the Pain of Visceral Disease, Brain, 1893, p. 1; 1894, p. 339; 1896, p. 153.

areas. Reference to Figs. 155 and 156 and the table compiled by Jacoby will illustrate these relations. Thus, if it were desired to influence

Fig. 155

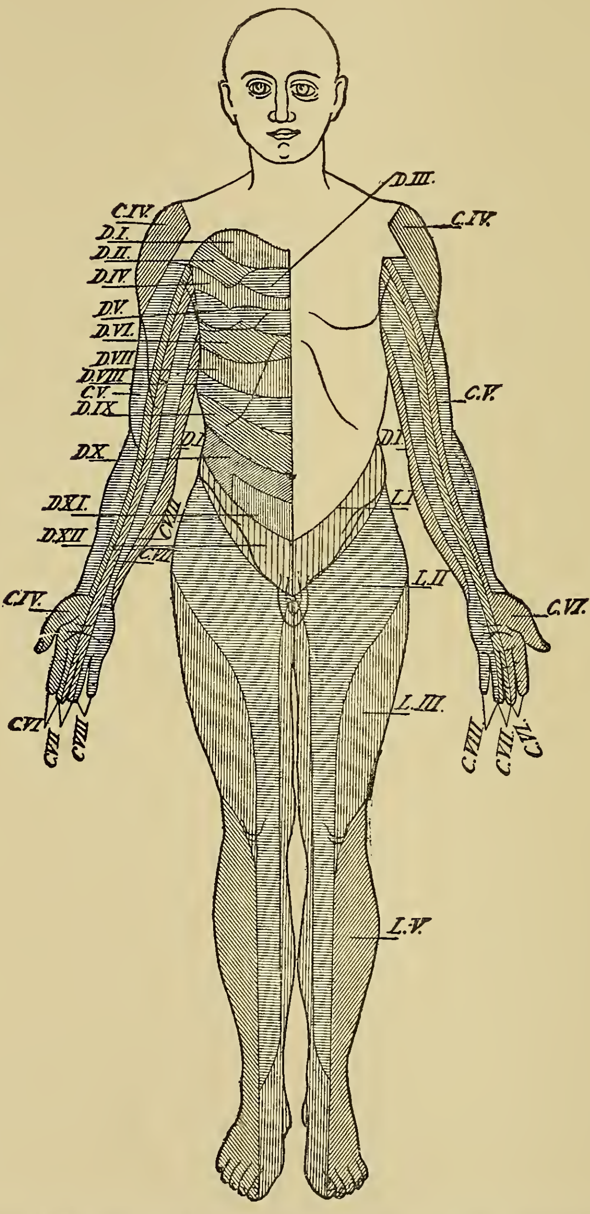


Diagram of skin areas corresponding to different spinal segments. Roman numerals refer to nerves. (From Tyson, after Starr. Trunk areas from Head.)

the stomach, the active electrode should be placed over the areas marked D^5, D^7, D^8, and D^9.

Fig. 156

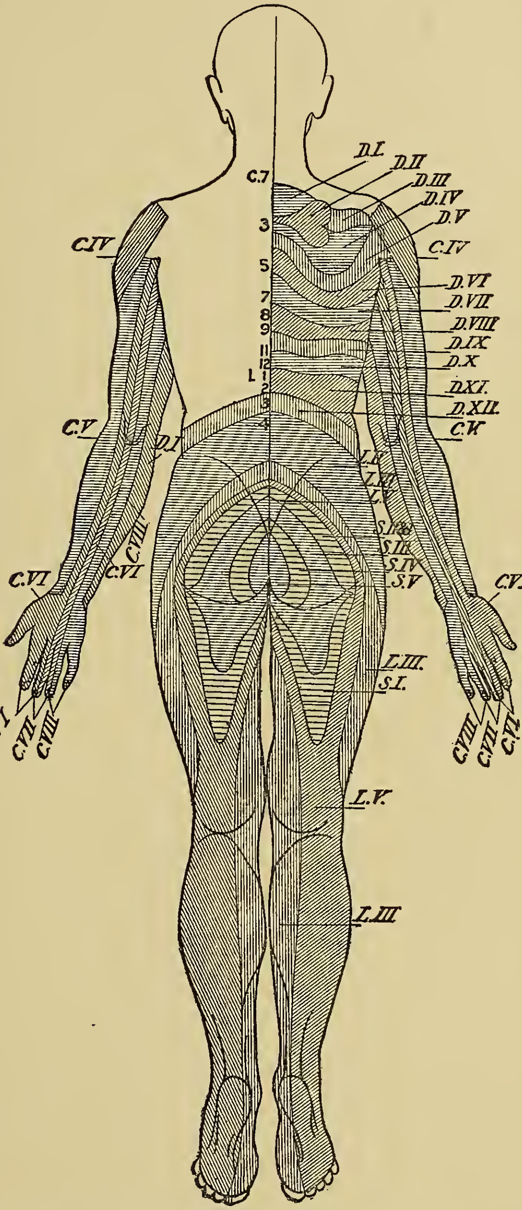
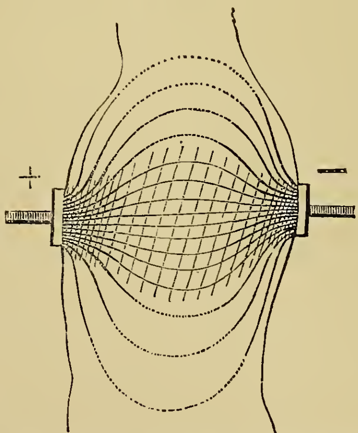


Diagram of skin areas corresponding to different spinal segments. Arabic numerals refer to vertebræ; Roman, to nerves. (From Tyson, after Starr. Trunk areas from Head.)

Table Giving the Viscera that are Related to the Various Skin Areas Shown in Figures 155 and 156.

	Heart.	Lung.	Stomach.	Intestine.	Rectum.	Liver and gall-bladder.	Kidney and ureter.	Bladder (mucous membrane and neck).	Bladder (overdistention and ineffectual contractions).	Prostate.	Epididymis.	Testis.	Ovary.	Appendages.	Uterus (in contraction).	Uterus (lower segment and os internum).
D 1	×	×														
D 2	×	×														
D 3	×	×														
D 4		×														
D 5		×														
D 6			×			×?										
D 7			×			×										
D 8			×			×										
D 9			×	×		×										
D 10				×		×	×			×		×	×		×	
D 11				×			×		×	×	×			×	×	
D 12				×			×		×	×?	×			×	×	
L 1							×				×			×	×	
L 5										×						
S 1								×?		×						×?
S 2					×			×		×						×
S 3					×			×		×						×
S 4					×			×								×

Fig. 157



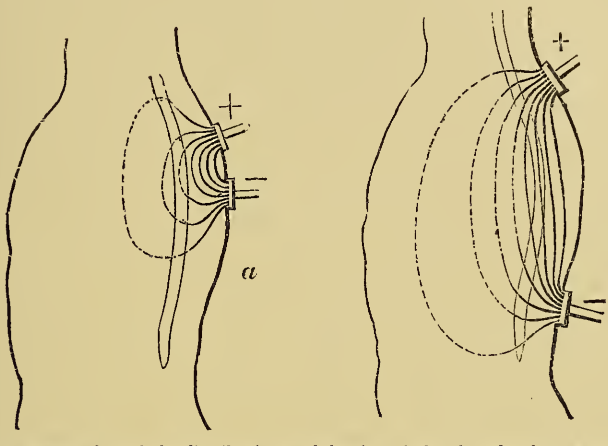
Schematic representation of the density of the current in its transverse passage through the body. The ineffective threads of current are dotted. The approximate zone of greatest density is shaded. (Erb.)

The size of the electrodes used is of importance. Reference to the remarks on current density and diffusion (p. 109) will emphasize

this statement. The following rules (modified from Turner) should prove useful:

To affect organs that are deeply situated (stomach, spinal cord, etc.) large electrodes and large current strengths are required; and the electrodes should be placed in such positions as to have the organ directly between them (Fig. 157). They should, as a rule, be far apart (Fig. 158).

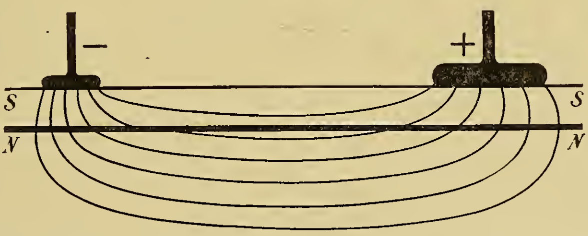
FIG. 158



Schematic representation of the distribution and density of the threads of current with regard to their entrance deeply into the tissue (in this instance, into the spinal cord): *a*, when electrodes are in close proximity; *b*, when far removed from one another. (Erb.)

To affect a small superficial structure, such as one of the peripheral nerves, the active electrode should be small (Fig. 159) and well pressed down upon the nerve. The indifferent electrode (Fig. 159) should be large.

FIG. 159



S, *S*, represents the skin; *N*, *N*, a nerve trunk. The density of the current under the small or negative electrode is much greater than that under the large or positive electrode.

If very strong currents are to be passed through the skin, it is essential that the electrode in contact with the skin be large. Large electrodes do not cause as much pain as small ones. Whenever the polar action (p. 132) is desired the indifferent electrode should be far removed from the part being treated (Fig. 116).

DOSAGE

When the galvanic current is employed the current strength employed can be exactly estimated by means of the galvanometer or milliamperemeter (Fig. 44). By dividing this current strength, estimated in milliamperes by the diameter of the electrode, we obtain the current density. Stintzing considers the limits of safe therapeutic dosage to lie between 0.5 and 50 milliamperes, with an electrode surface of from 3 to 500 square centimeters. For most purposes 5 to 10 milliamperes are sufficient. As has been said previously (p. 133), very strong currents are harmful excepting when employed for electrolytic action or for their psychic influence.

The strength of the faradic current is usually measured by its effect, and we speak of it as strong, medium, or weak, according to the effects produced upon a normal individual. Thus, a current that would produce a marked tetanic contraction of a normal muscle would be a strong current; one that would produce but a feeble contraction or none at all, a weak current. For purposes of comparison we can determine the length of the secondary coil necessary to cover the primary before an effect is produced, or if the extra current is being used, the length of primary coil that is not covered by the secondary. This only applies when the sledge coil of Dubois Reymond is used (Fig. 68). The same principle can be applied to the sliding tube (p. 93) if that is used.

Instruments have, however, been devised to measure respectively the E. M. F. and current strength of secondary coils. For the former that known as the electrostatic voltmeter, devised by Lord Kelvin, may be used, while for the latter the instrument invented by Sloan is the most convenient. This may also be used to measure the sinusoidal current (see also page 212).

CHAPTER XII

GENERAL RULES FOR USING THE STATIC CURRENT AND HIGH FREQUENCY CURRENTS

STATIC CURRENT

Care of the Apparatus.—As moisture or dampness interferes with the action of the static machine, it is important that it be kept in a room in which the air is dry. A dry house and a sunny room are of great importance in locating the apparatus. During spells of extremely damp weather, however, it is next to impossible to keep the air within the case dry unless one of certain other measures to absorb moisture is used.

Methods recommended for this purpose are: (1) To fill a large fruit jar with well-mixed, finely cracked ice and salt in about equal proportions, and after wiping the surface of the jar dry, place it upon a plate within the case and close. The moisture within the case quickly condenses upon the jar, the air is dried, and the machine will charge. This method, of course, can only be used when the air is already overcharged with moisture which we wish to remove. The succeeding methods are designed to prevent the air becoming too moist. (2) The keeping of calcium chloride within the case. This has the disadvantage, after the machine has been in use for some time, of forming a sticky coating upon the glass plates, which impairs the capacity of the machine. Chlorine gas, if commercial calcium chloride is used, may be generated and is also injurious in its affects. If used at all, chemically pure chloride of calcium should be used. (3) Snow, who has had a large experience with static machines, advises the use of ordinary calcium oxide or quicklime. This should be placed in an open box which is covered on all sides with two thicknesses of good muslin, otherwise dust will fly about and coat the plates. The box should be large enough to hold about twenty pounds of lime, which should be changed under ordinary conditions about once monthly. During seasons of prolonged damp weather it may be necessary to change it more frequently. The indications for changing would be a disposition for the machine to lose its charge or to excite less current than it formerly had been doing. Coolidge[1] states that sulphuric acid is superior to all, three or four pounds of the commercial acid in a glass vessel being placed within the case. Dobie,[2] of London, substantiates him in this, having had no trouble with his machine in the damp climate of that place. He seals all the joints

[1] Journal of Advanced Therapeutics, August, 1904, p. 500.
[2] Ibid., December, 1904, p. 717.

of the machine with strips of rubber plaster, and places a hygrometer within the case; when this registers 50° he changes his acid, first thoroughly airing the case and drying the metal work.

When possible the temperature of the room should be from 60° to 70° F. In spite of these measures, after a machine has either been in use for a long time or proper care has not been taken of it, it may not work satisfactorily; it is then necessary to *renovate* it. When possible the manufacturer of the machine is the best one to do this. If he is not available, it may be accomplished as follows: The metal parts and plates of the machine must be thoroughly dried. This is best done by removing the top and ends of the case and placing it where the sun can shine upon them for several hours. This may be all that is required. If the machine is of the Wimshurst-Holtz type[1] (pp. 36 and 38), it will be well at this time to remove the plates and give them a coating of the best varnish. Instructions may be obtained from the manufacturer as to the proper manner of removing the plates.

If the machine cannot be dried in the sun and it cannot be taken apart, it may be dried by taking a yardstick about one end of which is wrapped a piece of chamois skin and carefully wiping the parts with it; after which fresh lime should be put within the case. In addition to the procedures above described the metal parts within the case should be lacquered. A reserve set of these parts may be always kept on hand. The external metal parts, such as the prime conductors, discharging rods, etc., should at all times be kept well polished and free from dust, and the bearings well oiled. It should be noted from time to time whether friction either between the plates or between the plates and combs is taking place. When such is the case they should be adjusted to avoid this. Chafing of the revolving plates against the stationary ones is indicated by white spots near the circumference of the revolving plates. Before putting one's head within the case for any purpose, the door should be left open for a time, in order that the irritating gases which are within it may escape (see also p. 40).

It is important, in order that the machine does not discharge, that when not in use the discharging rods be kept widely apart. In the Holtz type of apparatus some device is necessary to excite the initial discharge; this is usually a small Wimshurst (Fig. 160, *b*), which may be placed in an apartment in the larger case, where it will not receive the action of the corrosive gases (p. 278). A typical machine of this type is shown in Fig. 160. A machine which is kept properly, the directions above given being followed, should not discharge for months; if, however, for any reason it has discharged, the following directions are given by Snow[2] for charging:

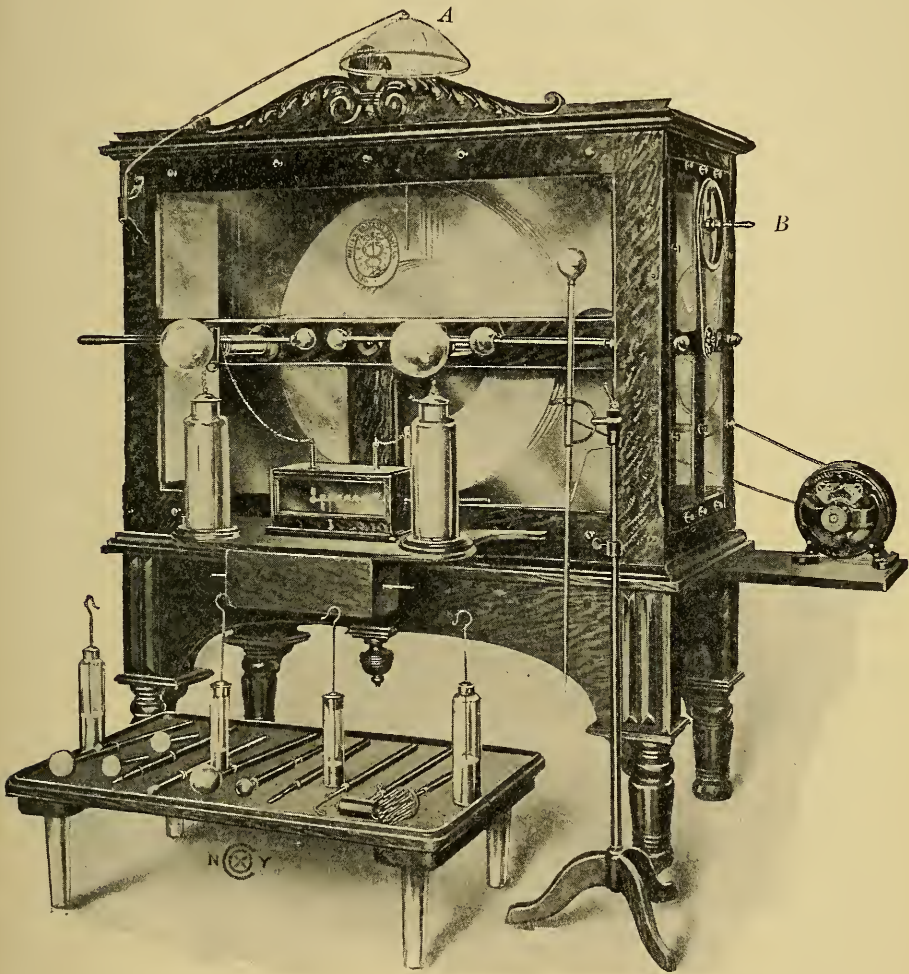
"1. Make the necessary connections, which vary with the make of different manufacturers, to place the Wimshurst in connection with the opposite sides of the Holtz.

[1] The Töpler-Holtz machine is that most used, and is self-exciting. The Wimshurst machine is very little used excepting as an exciter in machines of the pure Holtz type, as in Fig. 160.

[2] Static Electricity, p. 21 et seq.

"2. Separate the balls of the discharging rods about one-half inch and give the Wimshurst several vigorous turns before starting the Holtz (if the Wimshurst is operated by hand).

Fig. 160



Static machine showing Wimshurst machine on right hand side of case just below crank *B*, for charging. Hand power is used for this, supplied by crank *B*. Crown electrode shown at *A*.

"3. Next start the machine, at the same time moving the Wimshurst rapidly, and almost instantly a current of sparks will pass and continue when the Wimshurst is at rest. The machine is then charged.

"4. Cut the Wimshurst out of circuit and gradually separate the discharging rods, allowing the machine at the same time to run rapidly until a maximum charge is obtained."

14

If the charge is not excited, employ the following maneuvers:

"1. When the Wimshurst fails to give the usual one-half inch or longer spark, if revolved several times in the opposite direction and then reversed the current may be promptly excited. If when rapidly moved the Wimshurst will not generate a spark between the balls of the discharging rods at least three-eighths of an inch in length, it will cost a struggle to get the charge. One-half inch will usually succeed.

"2. Having carefully removed with a dry cloth or chamois all dust and moisture from the exposed metal parts of the machine in connection with the circuit, separate the balls of the discharging rods so a spark will pass when the Wimshurst is revolving rapidly. While rapidly turning the Wimshurst, start the Holtz slowly, little by little increasing the length of the spark gap, when after an instant, if sparks continue to pass between the balls, suddenly increase the speed of the Holtz, and the machine will either charge or the sparks cease passing. Shorten the sparks gap a trifle and repeat the maneuver. If this plan is tried over and over again, turning the Wimshurst very rapidly, starting the machine very slowly and then increasing the speed, success will often reward the effort."

If these maneuvers, after a fair trial, do not succeed, put the machine in order and replace the calcium (p. 207).

If the humidity is near 80 per cent. and there is no means of cooling the room and condensing the moisture, it will be useless to continue; if, however, success is attained by one of the above plans, and it is desired to use the machine for some time, do not let it stop nor close the conducting rods to within one-half inch of each other until it is not desired to use it further, then have it renovated.

The mica plate machines do not need as much care as the glass plate ones do, and also, in the author's experience, do better in damp weather.

The *polarity* of the machine may suddenly change, *i. e.*, the positive prime conductor becomes negative. This has been termed the "reverse of the static charge." For this reason the operator should ascertain the polarity before making the connections for treatment. He should also know how to determine which is the positive pole. This may be done by starting the machine with the sliding rods in contact; they should then be drawn apart, when it will be noticed that the stream of sparks is bright near the positive pole and of a violet tint near the negative. Again, if the rods are drawn apart just so far that a spark will not pass, the appearance of the discharge from the two poles will differ, viz., from the negative will be seen a fantail discharge radiating in straight lines from the ball, while from the positive it has a broken, tree-like appearance.

Another simple and efficacious method is to bring a stick of wood near to the large balls; the current from the positive side will follow the wood, but from the negative side none will pass.

If for any reason it is desired to have the positive charge remain constant, the following procedures may be used to again reverse the

charge when a change of polarity has occurred: Discharge the machine, bring the sliding rods close together, and give the positive end a jar, which may dislodge the charge and cause it to shift. In some cases this may have to be repeated several times. Another plan is to lift slightly the positive side of the machine and allow it to drop with a jolt. If these measures are not effective open the doors of the case to admit the outside air to the plates.

The *groundings* in connection with administering the static current are important. When using either indirect sparks, breeze, spray, brush discharge, high frequency current, or the wave current, it is necessary, if the best effects are produced, to ground the side of the machine not connected with either the patient or platform. This may be done by connecting with either the water or gas pipes of the house, excepting when they are connected with wiring for electric lighting or power, in which case the static current would melt the fuses and break the circuit. In such cases a wire may be carried to the cellar and connected with an iron rod driven several feet into the earth. The effects are intensified if the two groundings, viz., the pole of the machine not connected with the patient and the operating electrode, are at points removed from each other. Thus, if the water and gas pipes enter at opposite sides of the house, both can be employed, one for the machine and the other for the electrode, or the wires and iron rods above mentioned may be placed at separated points.

The fact that the resistance of the skin becomes less, and hence the current strength stronger, during the passage of the current should be remembered (p. 107).

Electrical treatment as a rule is contraindicated in those with fever, who are much debilitated (as from cancer and tuberculosis), very old people, and in menstruating or pregnant women. Further precautions to be observed in using other forms of current are given on pages 194 to 206.

Methods of Employing the Static Current.—The methods of applying the static current in the treatment of disease are known as convective, disruptive, and conductive discharges.

Convective discharges include static electrification, interrupted or constant, also termed the static bath and static insulation, the breeze and spray when given off from metal electrodes, either single or multiple; the brush discharge administered from resistance electrodes usually of wood, and high frequency discharges from the glass vacuum tubes.

Disruptive discharges comprise sparks, whether long, short, or friction.

Conductive discharges are the currents derived from the static machine comprising the static induced and static wave currents and their modifications (Snow).

Each of the forms of the static current according to the technique employed may act as a stimulant, a sedative, and influence general nutrition. Usually, however, for local stimulating effects either sparks or the static induced current are employed; for sedative effects the

brush discharge and breeze or spray, and for influencing metabolism the wave current and static insulation. The methods of applying these different modalities are described on pages 227, 231, 243, 245, 257, 259.

Precautions and General Rules to be Observed.[1]—It must be remembered that the patient upon his first visit is apt to be nervous and timid; it is, therefore, important that he be assured that the treatment will not be painful, and the first few treatments at least should be very mild. The application of the static insulation is often a good way of gaining the patient's confidence. If for any reason it should be necessary to use sparks sufficiently strong to produce pain, he should first be warned that some pain will be produced. It is especially important that no accidents, as an undue strength of current, occur at the first visit. Always be sure that the machine is charged before arranging the patient for treatment.

Some patients do not stand static electricity as well as others; thus, now and then instead of the glow and feeling of well-being which usually follows the treatment, the patient is left chilly and depressed. These feelings usually disappear in a short time. Convective and disruptive discharges cause pruritus lasting several days in some people.

Wheals and blisters may also follow these applications. In patients whose circulation is not good a mottled appearance of the skin may follow the application of sparks. These disagreeable effects usually disappear as the general condition of the patient improves. It is important also that when the breeze (p. 243) is applied to the head celluloid pins or combs be not worn, and that the hair is not thickly matted, as it thus acts as a condenser. Neglect of these precautions may cause the hair to catch fire. Such a case is on record, a crown electrode (Fig. 160) being used at the time.[2] Metal pins must also be removed when employing the breeze, or sparks may result.

The strength of the current and the length of time and frequency with which it is applied must be gauged by experience and the feelings of the patient; as has been said, it is well always to begin with weak currents and gradually increase the strength if required. An overdose or too prolonged treatment may be followed by a feeling of weariness and desire for sleep. This is relieved always by rest. From fifteen to thirty minutes is the usual duration of a seance when constitutional effects are desired. In employing sparks, remember that when applied to bony prominences or motor points they are painful. They also cause considerable pain in acute inflammatory conditions. Vigorous sparks should not be applied about the head or face. Daily treatments are usually indicated for the first few weeks, the period of time between being lengthened as the patient improves. In acute conditions two applications daily may be of service (p. 206).

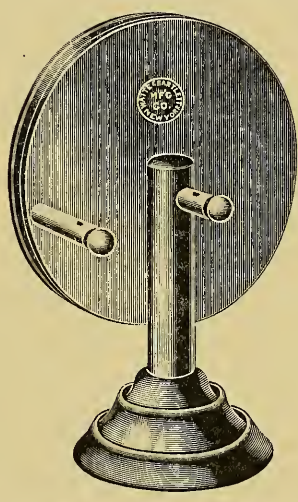
[1] These rules also apply to the use of high frequency currents; see also page 213.

[2] Journal of Advanced Therapeutics, November, 1910, p. 517.

HIGH FREQUENCY CURRENTS

Forms of Currents.[1]—The forms of high frequency current employed in medicine are the D'Arsonval (p. 99), Hyperstatic (p. 214), Resonator (p. 101), and Tesla (p. 103). The former, while of large amperage, is of much lower potential than the others, and cannot be used to give an effluve. The effluve is a discharge similar to the static breeze, spray, and brush discharge, the sensation of the patient being similar (pp. 243 and 245). It appears as a cylinder of purplish light from one to ten inches in length; if brought too close to the patient, sparks will pass. It produces marked local and reflex effects, as do the similar discharges derived from the static machine, by the bombardment of the body by the rapidly moving ions which constitute the effluve (pp. 51 and 52),

Fig. 161



Piffard's high frequency spiral, for use with static machine in producing the D'Arsonval current.

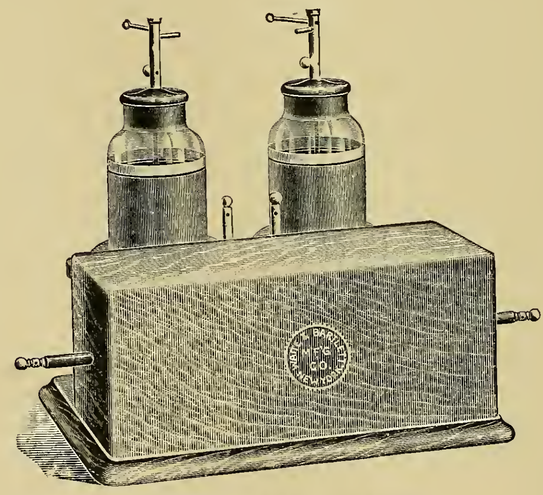
as well as by the action of the liberated ozone, and the possible action on the cells by the current itself (p. 140). To obtain this from a high frequency apparatus either the hyperstatic transformer, resonator, or secondary of the Tesla coil must be used. While general constitutional effects (p. 135) may be obtained from the primary coil of the Tesla apparatus, the current from the D'Arsonval coil (p. 219) is of special value for this purpose.

Various means may be employed to obtain the high tension current necessary to generate high frequency currents. Thus, the static machine may be used, the Leyden jars being put in place, and the ends of the solenoid attached to the outer coating. On the negative side the outer

[1] The static induced and wave currents are practically high frequency currents (pp. 101, 231, and 258).

coating may also be grounded, which increases the effect. This gives the D'Arsonval current of low potential. Such an appliance is shown in Fig. 161. According to Piffard,[1] with such connections a fourteen-plate machine revolving with a speed of 400 revolutions per minute will give a current through the patient of 150 milliamperes. In using this the discharging rods should be in contact when the machine is started and then gradually separated until a spark gap of sufficient length to produce the desired effect is obtained. This is usually one of 3 to 4 inches. The greater the spark gap, the greater the effect. This current so obtained may be administered by either metallic electrodes, glass vacuum electrodes (Figs. 192 and 197), autoconduction or autocondensation (pp. 262 and 263), according to the results desired. An apparatus for obtaining a current of much higher potential than the D'Arsonval with a static machine has also been devised by Piffard, and is known as the "Hyperstatic Transformer" (Fig. 162). This consists of a fine wire coil concentric

Fig. 162



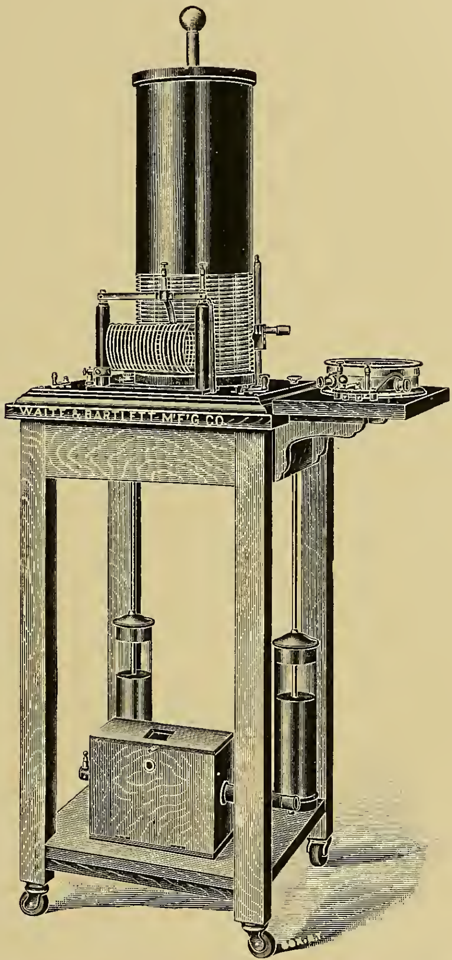
The Piffard hyperstatic transformer.

with the solenoid and the current obtained, known as the Hyperstatic, resembles somewhat the Tesla current, but the potential is not so high (p. 103). It has been found of special value in the treatment of skin diseases. Another means of obtaining a current of higher potential than the D'Arsonval is the use of the resonator (p. 101), which may be used in connection with a static machine. The machine should be run with the discharging rods widely separated and each connected with the inner coatings of the condenser or Leyden jar. Different types of resonators are shown in Figs. 78 and 163. Owing to the great noise produced at the spark gap, a muffler is a convenience; one is shown in Fig. 164.

[1] New York and Philadelphia Medical Journal, June 16, 1906, 1219.

A superior method to the static machine for all purposes, except when constitutional effects are desired, is the use of the Rhumkorff coil (p. 94). As it is not affected by the weather (p. 207), it is surer, and as it occupies less space, it is more convenient. The D'Arsonval current obtained from a coil is of lower potential but higher amperage

Fig. 163

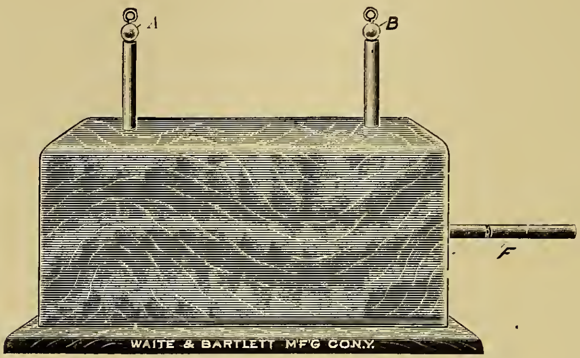


Oudin resonator and D'Arsonval high frequency apparatus.

than that obtained from the static machine. According to Piffard (*loc. cit.*), 250 milliamperes is the limit of an ordinary sized static machine, while 500 to 1000 milliamperes may be obtained from a coil. The resonator may also be employed in connection with the D'Arsonval coil when the Rhumkorff coil is used (Fig. 165). The resonator gives a

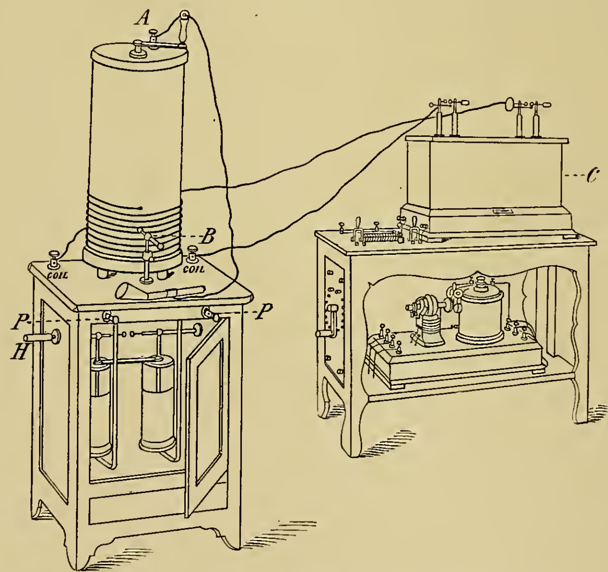
fine effluve, and is very useful for local treatment; it is usually applied by the monopolar method, with either a metallic point or glass vacuum

Fig. 164



Spark muffler. The upright posts *A* and *B* on the muffler are connected with the sliding poles of the static machine, which should be drawn apart in order to prevent any discharge between them—the spark being regulated by the handle *F* of the muffler.

Fig. 165



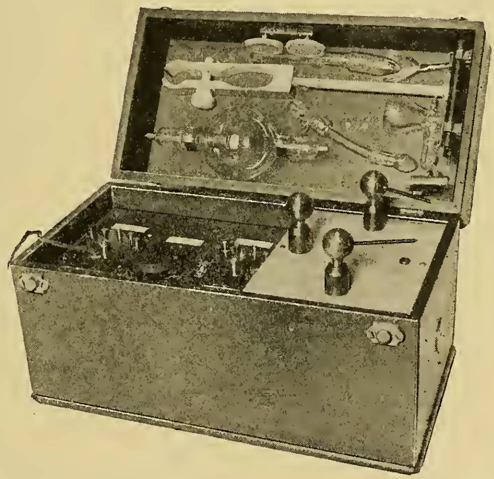
Oudin type of resonator operated by coil. Points marked *P* are for connections when D'Arsonval current is to be applied to patient; *A* shows attachment when resonator current is used: *B* is a movable contact which glides over the solenoid and regulates the current; in other words, tunes the resonator.

electrode (Figs. 192 and 197). The technique of its application is given on page 235. A coil requires the use of an interrupter (p. 95), which is of some inconvenience, and the alternating current from a dynamo

(pp. 81 and 414) is now much employed. When this is used the current tension must be increased by means of a step up transformer (p. 85), which while it increases the voltage does not increase the frequency. From the transformer the current goes to the condenser (p. 32), the discharge of which increases the frequency but not the voltage, and causes the current to become oscillatory (p. 94). From the condenser the current passes to the primary coil, being interrupted by means of the spark gap, which induces a current in the secondary coil of great frequency (Fig. 80, pp. 100 and 103).

The most convenient source of supply is the street current; for all purposes the 110-volt direct is most useful, but for the high frequency alone the 110-volt alternating is preferable. If the direct is used it must be changed into an alternating current by means of a rotary converter (p. 87). The 220-volt currents may also be used. Storage batteries (p. 59) may be employed to supply the current, and may be used where a street current is not available.

Fig. 166



The ceco coil; portable for x-ray and high frequency uses.

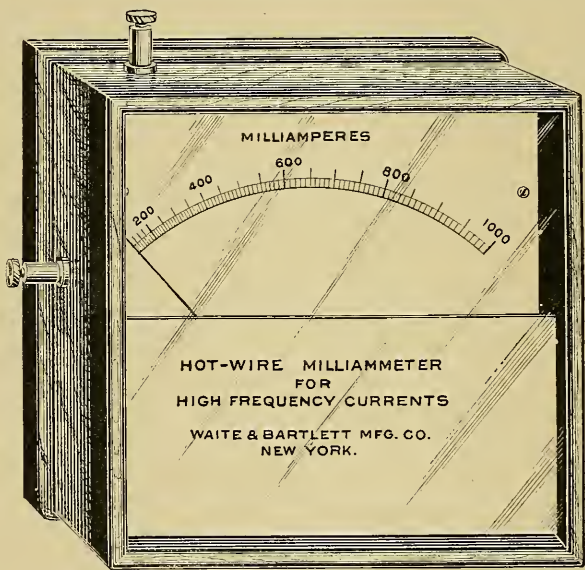
The Tesla current (p. 103), which is of high tension and amperage, is now being employed considerably in this country, and a number of different forms of apparatus are being made of this type. The dynamo (see above) is employed as the source of the current. Many modifications of the high frequency current can be obtained from these machines. Portable coils of the Tesla type can also be obtained (Fig. 166).

Physical Properties of Currents (see also pp. 98 and 99).—It is well to bear in mind the remarkable *physical properties* of these currents, viz.: They do not require a closed conductor or complete circuit for their

transmission; they are transmitted as electric waves through the air, and will illuminate vacuum tubes held at a considerable distance; ordinary means of insulation are not applicable, and they will readily pass through glass of considerable thickness; currents of extreme voltage (as high as 2,000,000) may pass through the body without pain or danger (p. 136).

That currents of considerable strength may so pass through the body may be shown if two individuals will each hold one terminal of an incandescent light while each is also connected with a terminal of a Tesla coil, when the current passes the lamp will be illuminated. If an animal is placed within a large solenoid through which such a current

Fig. 167



Hot-wire milliammeter for high frequency currents.

is passing, powerful currents will be induced in the animal without pain or discomfort (p. 263). Thus, if a man so placed holds the terminals of an incandescent lamp, one in each hand, it will be illuminated.

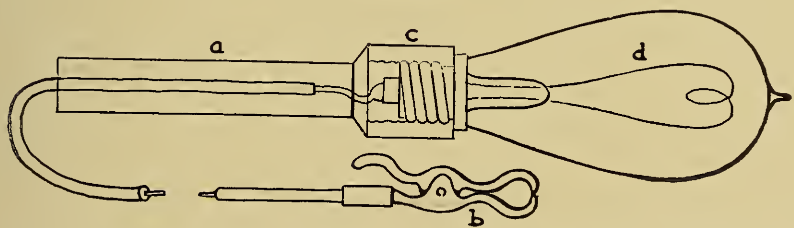
Different forms of coils give currents of different amounts of voltage, amperage, and frequency, according to the form of coil and source of current supply, viz., static machine or coil (pp. 100 and 213). In general it may be said that currents of a comparatively low voltage but greater amperage are obtained from the D'Arsonval coil and primary of the Tesla. The resonator attachment to the D'Arsonval coil increases the voltage and lessens the amperage. The current from the secondary of the Tesla coil is of still higher potential, while that from the hyperstatic transformer (p. 214) attached to a static machine is also

high, but of very little amperage. Different physiological action has been asserted to be caused by variations in the relative voltage and amperage. What these are is still in the experimental stage. Our present knowledge seems to be that for constitutional and metabolic influence the currents of low voltage and high amperage are preferable; for local effects the reverse is the case.

The higher the frequency, the less discomfort is caused the patient. To obtain constitutional influence, the amperage should be high enough to cause illumination of a lamp, as shown on page 218, to illuminate a Geissler tube or vacuum electrode brought within three or four feet of the patient connected to a terminal of the coil, and if the Tesla coil is used, to produce *x*-rays sufficient to give a good picture of the thorax or shoulder-joint.

The voltage should be high enough to give a fine effluve at a distance of eight inches or more from the patient, which distance can be reduced to four inches without sparking the patient. It is advisable to measure the amount of current used; for this purpose a hot wire meter (p. 79) may be employed (Fig. 167). Strong has devised a method which is less expensive and approximately gives the amount of current. It consists of employing a 16-candle-power incandescent lamp arranged as shown in Fig. 168. The amperage is indicated by the degree of light. A full illumination indicates the passage of 500 milliamperes; bright red, about 200 milliamperes; and a dull cherry red, 50 milliamperes.

Fig. 168



Lamp bulb hand-electrode. The insulated conducting cord is attached to the Tesla terminal by the clip *b*, and the current passes through the lamp *d*, and thence to patient *via* the metal handle *a*. (Strong.)

Contraindications to Use.—There is no practical method by which the exact frequency can be estimated.

Contraindications to the use of high frequency currents are the presence of low arterial tension, a degenerated heart muscle, acute inflammation of any of the viscera, infectious fevers, and advanced tuberculosis.[1] It is very important when administering the first treatment to a patient to remember that he may be apprehensive, therefore great caution should be used not to cause pain or discomfort. The high frequency spark is painful, and, if sufficiently strong, may cause an ugly burn.

[1] In incipient tuberculosis they may be of therapeutic value (p. 312).

The cords from the terminals should not be allowed to touch the patient, as sparks will frequently pass through the insulation (see also Rules for Static Current, page 212).

The strength of the discharge may be controlled by varying the strength of the current used to excite the coil, or by increasing or decreasing the size of the spark gap. The resonator discharge may be varied by throwing the resonator more or less out of tune. Connecting one side of the apparatus to the earth often increases the efficiency of the discharge.

CHOICE OF CURRENTS

For the treatment of motor paralysis Professor H. C. Wood used to give the following rule: "Use the current which gives the best contraction with the least pain." This is a good working rule when stimulation of muscles and nerves is desired. The faradic current should be employed if the muscles react to it, but in those cases in which faradic contractility is either much diminished or lost, the galvanic current should be employed by one of the methods described on page 224. When it is at hand, the static induced current of Morton (p. 231) is an efficient means of producing muscular contractions in cases where faradism is applicable. It possesses the great advantage of doing so with little or no pain. The same may be said of the sinusoidal current (Fig. 151), and in addition it may be used to stimulate degenerated muscles (due to lesions of the peripheral neuron) as well as in those cases (lesions of central neuron) in which faradism is usually employed. Jacoby says: "For all therapeutic stimulation of muscular tissue, when little or no sensory stimulation is desired, the sinusoidal current should be chosen." The disadvantage of these latter two forms of current is that special apparatus is required to produce them, and consequently they are not usually at the command of the general practitioner, neither is the apparatus portable, and they can only be administered in the office. It is usually, therefore, a choice between galvanism and faradism.

Galvanofaradization (p. 123) is recommended when it is desired to act upon deep muscles and viscera, as the stomach and intestines.

For the stimulation of sensory nerves, the faradic current with the dry brush electrode (Fig. 117) is preferable. Static and high frequency currents are also useful for this purpose (pp. 128 and 129). Any of the forms of current may be used to relieve pain. Rockwell[1] gives the following rule: "The pain that is not increased by pressure, and especially if pressure affords any manner of temporary relief, is far more likely to be benefited by the faradic or sinusoidal, or by any of the high frequency or high potential manifestations of electricity, while painful parts, sensitive to pressure, barring the hyperesthesia of hysteria, are, as a rule, affected

[1] Medical and Surgical Electricity, edition of 1903, p. 336.

more favorably by the galvanic current." The sinusoidal current is most useful in the treatment of paresthesia, hyperesthesia, headaches, neurasthenic pains, and sometimes in neuralgia. In the latter, however, the galvanic current is the more apt to be useful. The static current is efficacious in the headache of neurasthenia and the various pains which are symptoms of the great neuroses, and also in relieving the pain of the occupation neuroses and muscular rheumatism.

To relieve muscular spasm the galvanic current is probably most useful, although any of the forms of current may be of benefit in different cases. Rockwell speaks very highly of galvanofaradization (p. 123), and considers it the most efficacious of any. To obtain electrolytic or cataphoric effects the galvanic current is usually employed (pp. 113 and 114). High tension currents may also prove of use (p. 115). When it is desired to make a mental impression, as in hysteria, either the static or high frequency currents are most useful; if it is not at hand, the rapidly interrupted faradic current ranks next for this purpose. For the relief of local congestions and exudations, either the galvanic (p. 115), static (p. 124), or high frequency currents may be employed with advantage.

For the influencing of general nutrition and metabolism either the static or high frequency currents would seem from present indications to be the most useful (p. 135). The galvanic and faradic currents employed as general galvanization or faradization (pp. 250 and 252) are also employed for this purpose.

Methods of application to attain the objects mentioned above are detailed in the following chapters of this section and in Section VI.

CHAPTER XIII

METHODS OF PRODUCING LOCAL ELECTRIFICATION

We employ electricity locally to cause either stimulation or sedation, and to promote absorption of morbid exudations (pp. 113 to 129), and relieve congestion. The electrolytic and cataphoric effects may also be utilized for other purposes. These, however, will be discussed under separate heads (pp. 267 and 271).

STIMULATION

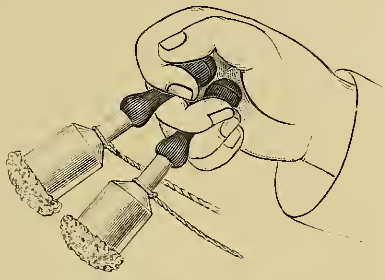
To stimulate, which is the action desired in cases of paralysis, we may employ either the faradic, sinusoidal, galvanic, galvanofaradic, static, or high frequency currents. The general indications when to employ each of these forms of current are mentioned on page 220.

Faradic and Sinusoidal Currents.—In using the faradic current to excite muscle or nerve we can employ it either rapidly or slowly interrupted. If the former is selected, one electrode of medium size (Fig. 113) should be placed at some indifferent point, as over or near the nerve trunk supplying the muscles being treated, while the other, of similar size, is, with a current sufficiently strong to cause contraction, brushed firmly over the muscles. Care must be taken to lift the electrode from the skin before each stroke in order to open and close the circuit and thus obtain clonic instead of tonic contractions, as would be the case if this were not done. An advantage of this method for those not expert is that no knowledge of motor points is required. As this method excites groups of muscles simultaneously, it has the advantage of saving time, but for the same reason it can only be employed when it is not desired to pick out individual muscles for treatment. By using the interrupting handle (Fig. 114) the rapidly interrupted current can be used when individual muscles are treated. In using the slowly interrupted current we may take both electrodes of equal and medium size in the hand, as in Fig 169; then, with a current just strong enough to produce contraction, the two electrodes are placed over the belly of each muscle, being treated one after the other. That is, if we were treating the muscles of the thigh, we would first place them over the rectus femoris, causing eight or ten contractions in it, then over the vastus internus, causing the same number of contractions in it, then over the vastus externus, and so on.

Another method is to place one electrode of good size at some indif-

ferent point, preferably over or near the nerve trunks supplying the muscles being treated, while the other electrode of smaller size is placed over the motor points of each muscle in turn, and contractions caused

Fig. 169



Method of holding electrodes in one hand. (Mills.)

as above described (Figs. 154 and 172). A combination of the influences of massage and electricity may be obtained by employing a roller electrode (Figs. 170 and 171) as the active one. This, of course, is rolled

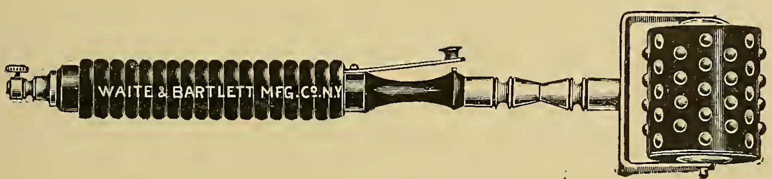
Fig. 170

Roller electrode.

backward and forward over the part being treated. The rapidly interrupted current should be used.

To produce excitation of cutaneous *sensory nerves,* we employ the dry metallic brush (Fig. 171), which is attached to one cord of the battery,

Fig. 171



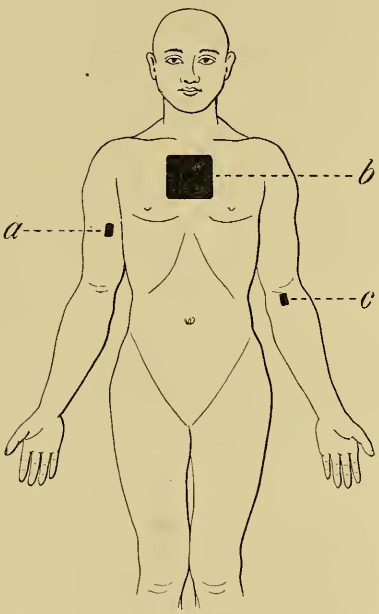
Roller electrode with point contacts.

while an ordinary electrode is attached to the other; the latter is placed at some indifferent point, while the former is held for a short time in the anesthetic area. If the area is a large one, the brush should be moved

about until the entire area is treated. The current from the secondary coil, preferably composed of long, thin wire (p. 128), rapidly interrupted, should be used. It should be as strong as possible.

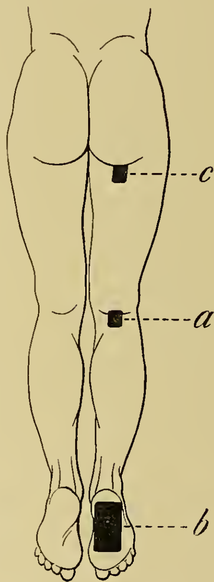
In cases in which it is desired to use a weaker current than the battery will give, we can still further diminish its strength by making the body of the operator a rheostat, as it were. This is done by placing one electrode on the body of the patient, while the physician takes the other in his hand; his other hand, which has been previously dipped in water, is then, as the active electrode, applied to the patient. Different forms of faradic apparatus are shown in Figs. 106 and 107.

FIG. 172



Proper position of the electrodes to obtain polar action in muscle or nerve. If stimulation is desired, the active electrode should be the kathode; if sedation, the anode: *a*, small active electrode over the biceps muscle; *b*, large indifferent electrode over the sternum; *c*, small active electrode over the median nerve.

FIG. 173



Showing the position of the electrodes in passing a current down a nerve, in this case the sciatic. The anode is placed above or below according as it is desired to have a descending or ascending current. The upper electrode could also be placed in the lumbo-sacral region: *a*, electrode in popliteal space, or, if it is desired to influence the branches, it may be placed on the sole of the foot; *b*, large plate electrode on sole of foot; *c*, electrode over sciatic nerve.

Galvanic Current.—The local stimulating effects of the galvanic current may be obtained by one of three methods, known as *stabile, labile,* and *interrupted* galvanization.

Stabile Method.—In this the current is made to flow steadily without breaking the circuit. The electrodes should be placed in the situations

desired while the current is at zero. It is then *gradually* increased until the desired strength, as indicated either by the milliamperemeter or feelings of the patient, is attained. After the current has flowed the length of time desired, it is again *gradually* reduced to zero. The electrodes must not be moved while the current is flowing. If the polar influence is desired, the kathode should be placed over the nerve or muscles which it is desired to stimulate, the anode at an indifferent point (Fig. 172), or if it is desired that the current pass through the length of a nerve, one electrode must be placed at its proximal end, the other at the distal (Fig. 173). If the leg is being treated, plate electrodes covered with sponge or felt (Fig. 110) may be used, as shown in Fig. 173.

If for any reason the current controller will not act to increase or decrease the current strength in a satisfactory manner, Jacoby describes the following method as useful: "Selecting the approximate quantity of current required, the operator applies one of the electrodes to the part to be treated and completes the circuit with the other electrode by applying its edge lightly to some hairy or thick-skinned part near the spot of intended application. This electrode is then gradually to be drawn over the part of high resistance (hair, thick skin) to that of lower resistance, at the same time allowing more and more of its surface to come in contact with the skin, until, the desired point of application being reached, the electrode rests firmly and flatly upon it. The removal of the electrode is effected in the reverse order." By gradually increasing the pressure we may also gradually increase the current strength, while a gradual decrease of pressure will lessen it.

Labile Method.—In this, one electrode is applied to an indifferent point (sternum, back of neck, or nerve supplying the muscles being treated), while the other is moved to and fro over the affected part. A firm, steady pressure should be exerted, the electrode must not be removed from the body, the current strength should be gradually increased and decreased as in the stabile method, and when stimulation is desired the kathode must be the active electrode. A certain amount of fluctuation of current strength is unavoidable, as it is impossible to maintain an exactly uniform pressure.

When used to promote the absorption of exudate and dissipate congestion, the stabile method is employed; for instance, if a joint is being treated the electrodes should be placed one on each side of the one being treated. For the removal of local congestion, the positive pole is usually placed over the affected area (p. 114).

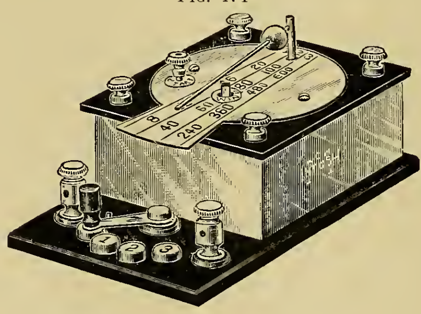
Interrupted Galvanization.—This may be secured by one of three methods. One electrode is placed at an indifferent point, as in the labile method, while the other (the kathode) is stroked with firm pressure over the part being treated, as in the labile method; but instead of being moved back without being removed from the skin, as in this method, we remove it, thus breaking the circuit, and closing it when the electrode is again brought in contact with the skin. This is done alternately

15

with a fair degree of rapidity until the desired number of muscular contractions thus produced is obtained. This method is similar to that described for the use of the rapidly interrupted faradic current (p. 222), and like it possesses the advantages of quickness and non-attention to motor points.

Another method is to hold one electrode firmly on an indifferent point, while the other (the kathode) is placed over the motor point of the muscle being treated; then by means of the interrupter on the handle of the electrode (Fig. 114), the circuit is alternately opened and closed until the desired number of contractions is obtained (Figs. 154 and 172). This is done to each of the affected muscles in turn. If an interrupting handle is not at hand, the same result may be obtained by repeatedly touching the muscle with the active electrode. Automatic contrivances for interrupting the current may also be used (Fig. 174). In cases where the muscles will not respond to the above methods we place the electrodes as just described; then by means of the current reverser (Fig. 93) the current is reversed the required number of times (Voltaic Alternatives, p. 120).

Fig. 174



McIntosh graduated automatic rheotome.

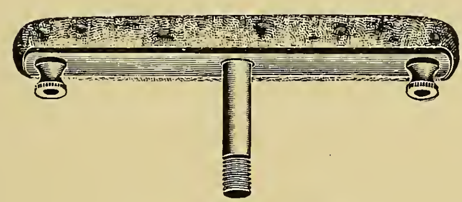
As a means of influencing the pneumogastric and cervical sympathetic nerves and other structures in the neck, a method was introduced by R. Remak, which he termed "galvanization of the sympathetic." As has already been said (p. 130), this is not possible, and the term *Subaural Galvanization* was substituted by De Watteville. The method consists in placing the kathode under the ear and the anode, which should be large, on the opposite side over the lower cervical vertebræ. If desired, the poles may be reversed, the anode being under the car and the kathode over the vertebræ. The subaural electrode should be small (about 3 centimeters in diameter, or as shown in Fig. 175), and pressed upward and backward toward the spinal column. Stabile applications *only* should be made. Different forms of galvanic apparatus are shown in Figs. 103 and 104.

Galvanofaradization is applied similarly to the faradic current. For a description of the apparatus necessary to obtain the combined currents, see page 123.

Static Currents.—The local stimulating effects of the static current are obtained either by employing sparks which may be used to relieve congestion by getting rid of stasis (p. 124), promote absorption, relieve pain due to congestion, and maintain the tone of inactive parts, or by the use of the static induced current (p. 231).

Sparks are elicited by one of the following methods, viz., indirect, direct, friction, and Leyden jar. The indirect and friction methods are those usually employed. The following directions and diagrams, mainly by Arnold Snow,[1] make the technique plain. There are two methods of administering indirect sparks, *i. e.*, with or without a discharging spark gap, the latter being usually used (Figs. 176 and 177).

Fig. 175



Electrode for sympathetic nerve.

1. With or without a discharging spark gap, the shepherd's crook, or rod (1 in diagram), should connect the positive pole[2] of the machine with the insulated platform. The nearer the crook is to the patient's feet the greater the effect. This may be further intensified by placing a metal plate on the platform and allowing the crook to rest on it. A chain may be used instead of the crook. This should be so placed that it is two or three feet from the machine and is not under a chandelier or other metal conductor. The patient should be placed on the platform so that he is directly opposite the prime conductor of the positive pole (+ in diagram). He may be seated or standing, according to the parts being treated.

2. The ground chain (3) should connect the negative pole of the machine to earth by a metallic conductor p. 211).

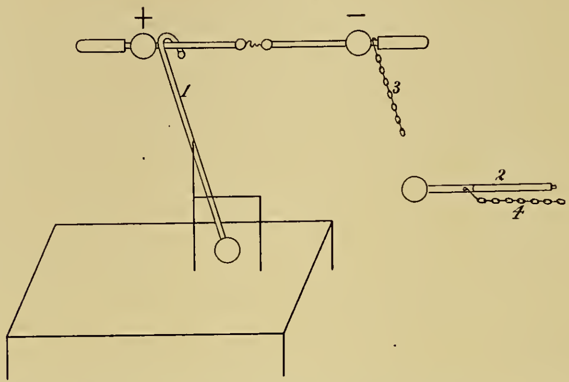
3. A ground chain (4) should also connect the metal ball electrode (Fig. 181) with the earth (p. 211). This should be held by the operator by the side of the electrode in order to keep it from touching the patient (Fig. 178). When a discharging spark gap, as in Fig. 176, is employed the effect is diminished. Sparks should be administered by a quick wrist movement,

[1] Journal of Advanced Therapeutics, August, 1906, p. 380.

[2] While this is the usual rule, better results are obtained in some cases by reversing this procedure. Both methods can be tried. Burch claims that the indirect positive spark with negative insulation is less painful.

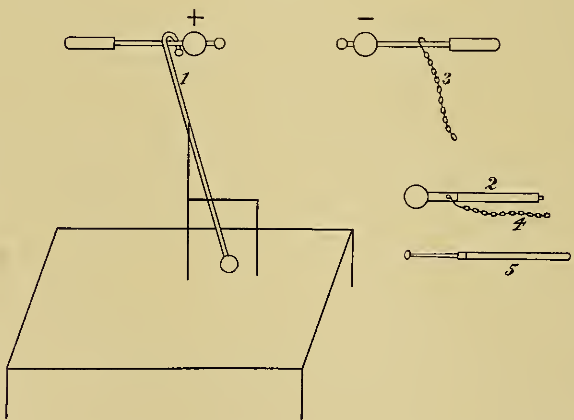
alternately approaching the part with the electrode until a spark passes, then quickly withdrawing it, so that each area of the part being treated

Fig. 176



1, shepherd's crook; 2, ball electrode held by operator; 3, ground chain to water pipe; 4, ground chain to gas pipe. (Snow.)

Fig. 177



1, shepherd's crook; 2, ball electrode; 3, ground chain to water pipe; 4, ground chain to gas pipe; 5, spark director held in operator's hand. (Snow.)

Fig. 178

Chain holder.

only receives one spark at a time, a rapid succession of them being disagreeable to the patient (p. 212). Their length should be governed by the part being treated, a half inch long for finger-joints, while

one three inches in length may be applied to the shoulder. Electrodes for this purpose are shown in Figs. 179, 180, and 181, the small one being used to administer them in the angles and clefts of the body. Snow's spark director (5 in Fig. 177) may also be used for this purpose, as it may be placed at the desired point and the sparks from the electrode allowed to strike it. Sparks should be thick, straight, and single.

Fig. 179

Ball electrode for administering sparks in clefts and angles of body. (Snow.)

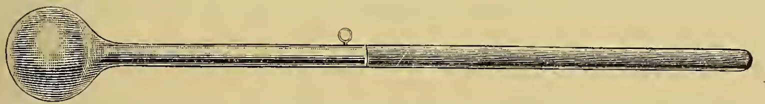
The length and consequent strength of the spark may be varied by increasing or decreasing the speed of the revolving plates, the length being in direct ratio to the speed; by increasing or decreasing the distance of the crook or chain from the patient's feet; by placing the discharging rods at varying distances—the farther they are apart the greater the length of spark; by the operator drawing off part of the cur-

Fig. 180

Ball electrode for administering sparks to hands or face. (Snow.)

rent when short sparks are desired, by placing one foot upon the platform and withdrawing it when strong ones are desired (this is the best method). They should not be applied to bony prominences, the breasts, nails, or genitalia. If the clothing is damp or of poor quality (containing considerable cotton), the patient may hold a woollen cloth or piece of paper or other non-conductor over the part being treated.[1] To influence

Fig. 181



Ball electrode for administration of sparks and friction sparks. (Snow.)

internal organs, make the application to the skin over them.[2] If muscles are being treated, they should be applied to the motor points. An electrode for this purpose is shown in Fig. 182). When the air is very damp

[1] It is not necessary to remove clothing for treatment with either the static or high frequency current.

[2] In this connection see also pages 140 and 201.

or for any reason the output of the machine is poor, the *direct method* may be employed (Fig. 183), as follows:

1. The discharging rods should be widely separated.
2. The patient being placed on the insulated platform, he either grasps the shepherd's crook or chain (1) in the hand, the other end being connected with the positive pole of the machine, or it may rest upon a metal plate on the platform, upon which the patient's feet with the shoes removed are also placed.

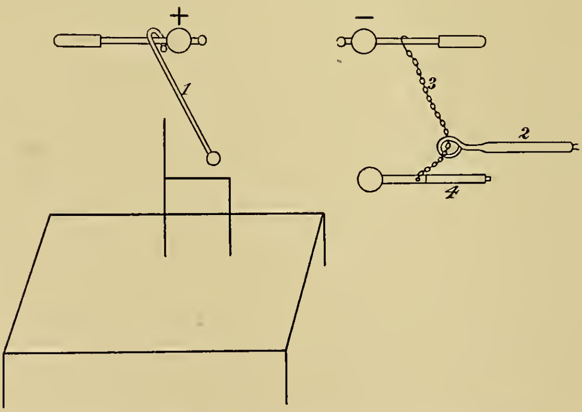
Fig. 182

Localizing static spark electrode for contracting individual muscles.

3. The spark is administered with a large metal ball electrode (4), which is connected with the negative side of the machine with a short chain (3), which is held away from the patient by the chain holder (2). Sparks produced by this method are sharp, thin, and painful.

A modification, consisting of the crook or chain being placed on the platform either under or beyond the patient's chair, is shown in Fig. 184. By this method the effect is milder (see Fig. 187 for further technique).

Fig. 183



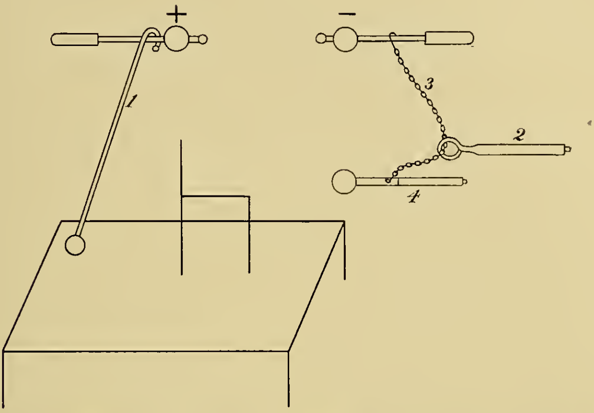
1, shepherd's crook held by patient; 2, spiral holder 3, chain from negative side to ball electrode; 4, ball electrode. (Snow.)

Friction sparks are administered by making the same connections as given for indirect sparks and rubbing the ball electrode rapidly with long strokes over the part being treated, it, of course, being covered by the clothing. A roller electrode (Fig. 185) may be employed for this purpose, but is not superior to the method given. This spark pro-

duces a feeling of warmth, and may be used to relieve pain if not deeply seated, as a mild counterirritant to stimulate the peripheral circulation, and in the treatment of anesthetic areas from any cause. The thickness of the clothing determines the length of the spark.

Leyden jar sparks are too severe for ordinary therapeutic purposes. They may be used when it is desired to make a strong mental impres-

Fig. 184

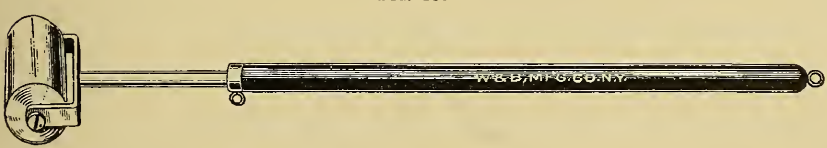


1, shepherd's crook; 2, spiral holder; 3, chain from negative side to ball; 4, ball electrode. (Snow.)

sion, or to arouse a lethargic patient (stuporous melancholia) hysterical trance, etc.). The connections are the same as for the indirect spark, with the addition of two Leyden jars (Fig. 186).

The *static induced current* (p. 101) may be used to obtain muscle stimulation. As it produces muscular contraction, varying in degree with the length of the spark gap, it also diminishes local congestion. This current was first used by W. J. Morton, of New York, and was

Fig. 185



Static electrode, massage roller.

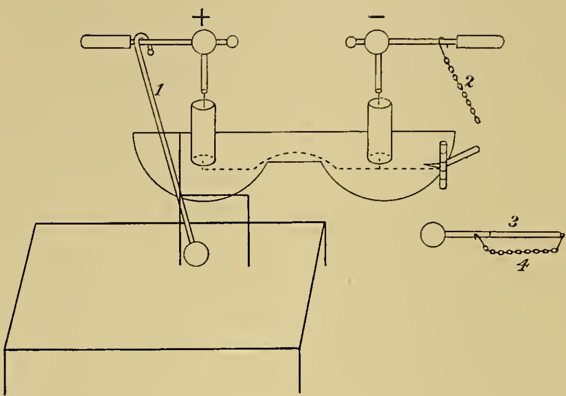
the first employment in medicine of a high frequency current. It may be administered by one of two methods:

1. By the use of electrodes such as would be used for applying either the faradic or galvanic currents. Morton[1] advises for the application of this current a modification of these electrodes as follows: "The metal, if a

[1] New York Medical Record. January 24, 1891, xxxix, 100.

plate, should be rolled back on itself at its edges so as to present a rounded peripheral contour, or, better still, it should be a ball of about one inch

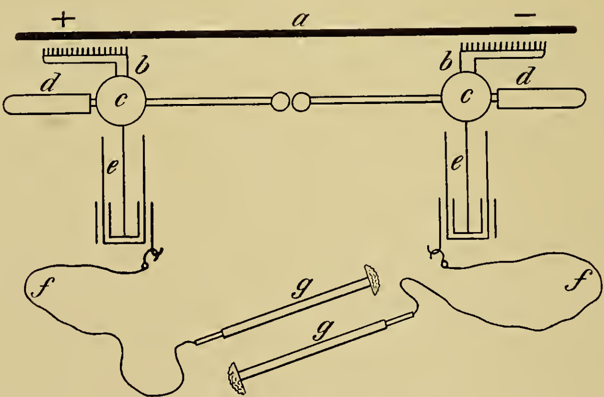
Fig. 186



1, shepherd's crook; 2, ground chain to water pipe; 3, ball electrode; 4, ground chain to gas pipe (Snow.)

in diameter; the handle of the electrodes should be long, and made of ebonite; the conducting cord should consist of a thick strand of fine wire, well insulated by gutta-percha." These precautions are necessary, owing

Fig, 187

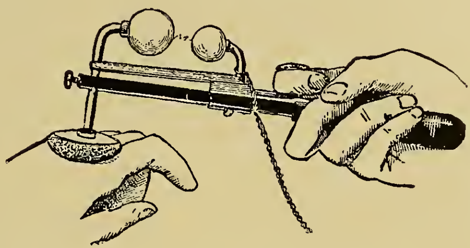


"Static induced current." Parts of static universal electrode separated. Person, condenser, and circuit breaker in same circuit, connecting rod between condensers removed, and discharging rod of machine serving as circuit breaker; but the circuit breaker is in the primary circuit, and the person in the secondary. The make and break in the primary is accomplished with a current in the secondary. (Morton.) *a*, rotating plate; *b*, *b*, collecting combs; *c*, *c*, prime conductors; *d*, *d*, discharging rods; *e*, *e*, Leyden jars; *f*, *f*, conducting cords; *g*, *g*, sponge or other electrodes.

to the great tension of the current and its consequent disposition to break down insulating barriers, which in the case of ordinary currents would

suffice to confine them to their proper conductors. To use the current, the discharging rods of the Holtz machine must be brought into contact and the connecting rod which unites the two Leyden jars removed. The two conducting cords are then attached to the outer coating of the jars (Fig. 187). The patient need not be insulated, and the electrodes

Fig. 188

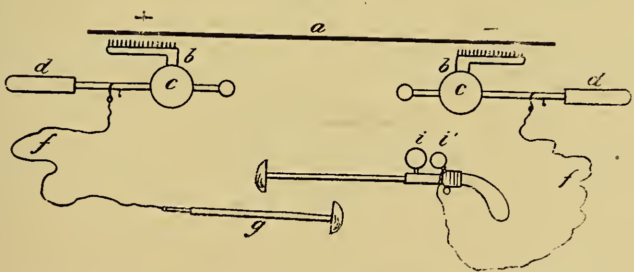


Terminal electrode as constructed in 1880; arranged for a moistened sponge or other terminal. The two adjustable brass balls constitute the circuit breaker; the spark passes between the two and a corresponding current produces characteristic electric reactions at the point of application of the sponge to the body. (Morton.)

are placed as in using either the faradic or galvanic currents. The machine is then set in motion and the discharge rods are slightly separated. The current is strengthened by increasing the separation.

2. By the use of the static universal electrode, sometimes termed the "pistol electrode" of Morton (Fig. 188). By this arrangement, instead of using the discharging rods as the circuit breaker we employ

Fig. 189

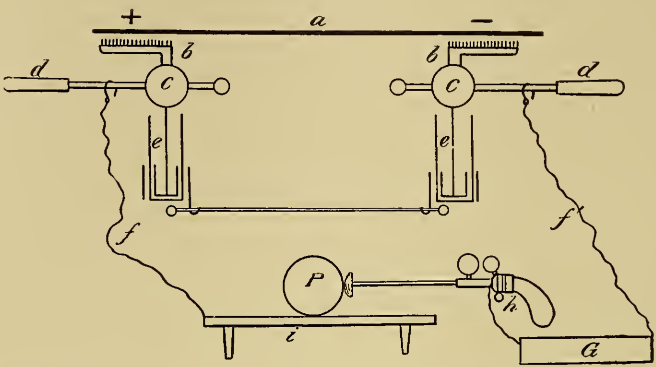


Static universal electrode. Interrupted primary circuit of a Holtz machine, without condensers. Parts lettered as in Fig. 187. *i*, *i*, static universal electrode in circuit. Upon grasping the two electrodes and drawing the two brass balls, *i*, *i*, of the circuit-breaking electrode apart a current is felt causing vigorous muscular contractions in ratio with the distance apart of the balls, *i*, *i*, and as long as sparks will pass between them. Patient insulated. Method applicable to small machines. (Morton.)

the two adjustable metallic balls on the electrode for that purpose. The distance apart of these and consequent strength of current which it is desired to have is regulated by the finger of the operator. It may be employed in one of two ways—either without condensers, when the arrangement is as in Fig. 189, or by using condensers, as in

Fig. 190. When using this electrode the patient must be insulated, one cord being attached to the insulating platform, while the other is grounded; only one electrode (the pistol electrode) is applied to the

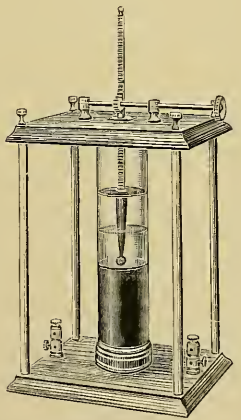
Fig. 190



Static universal electrode. In primary circuit grounded. Patient, condensers, and circuit breaker in same circuit. Patient on an insulated platform as in giving sparks. Lettering as in Fig. 187, except that *f*, *f* is grounded pole of machine and connection to platform; *P*, person insulated; *G*, grounded chain from universal electrode, having curved handle, to be held by administrator and applied upon the person of the insulated subject, strength of current graduated by the finger and adjustable balls of circuit breaker. (Morton.)

patient, and this must be also grounded by a metal chain passing to the same object on which the cord is grounded.

Fig. 191



Water rheostat. (Snow.)

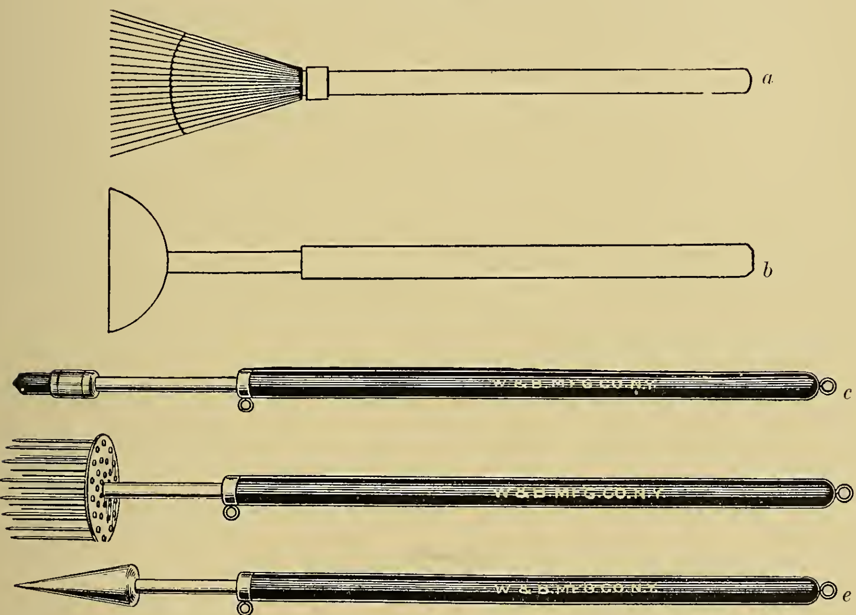
The electrode is applied to the motor points if the muscles are being treated, and to the affected region if it is desired to remove congestion.

It may be necessary to still further weaken the current than can be

done with the length of spark gap. Then some form of rheostat, as the water rheostat of Cleaves (Fig. 191), may be employed. If the Leyden jars employed are of different sizes it may be possible to give more current to one part than another. This current may be useful in humid weather, when a short discharging spark only can be obtained. As a rule, the wave current (p. 259), which can be employed for the same purposes, is superior. The static breeze and brush discharge may also be used to produce local stimulation (pp. 243 and 245).

To *stimulate* the *sensory nerves* of the skin, sparks may be applied to the anesthetic area, as described for motor nerves (p. 227), or we may employ friction sparks (p. 230).

FIG. 192

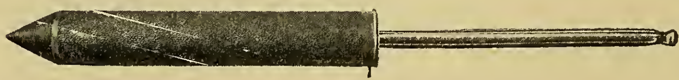


Effluve electrodes: *a*, wire brush electrode; *b*, bell electrode; *c*, carbon-point electrode; *d*, multiple-point electrode; *e*, single brass-point electrode.

Methods of Obtaining Local Stimulation by Currents of High Frequency.—For local action either the resonator or Tesla currents are preferable. They may be administered either in the form of the effluve (p. 213) or by the glass vacuum electrodes. If the former is employed, one of the forms of electrode shown in Fig. 192 may be used. Another useful type is shown in Fig. 193. The form selected should depend on object desired; thus, if a small area is to be treated, either *c* or *e*, Fig. 192, should be used; if a large area, *a* or *d*, Fig. 192. Fig. 193 may be used for either purpose. In administering the effluve, care must be taken to not bring the electrode too near the body of the patient, or a disagreeable

although harmless sparking may result. The electrode should be held some distance from the patient and gradually brought toward him until a stream of purplish light appears between the metal points and patient. As a rule, the length of the effluve must be such that merely a feeling of heat and as if air were blowing against the body is experienced by the patient. If a greater stimulation is desired, the electrode is brought closer, care being taken that it is not close enough to spark. Such an application causes intense hyperemia and even blistering. It may be used to stimulate indolent ulcers or produce an inflammation.

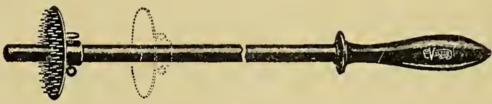
Fig. 193



Resonator electrode. This is a form of electrode designed to be attached to the Tesla coil terminals or to the Oudin resonator by a cord, just as are the regular vacuum electrodes. It gives a fine, long, soft effluve, and is used to apply the effluve or the spark. The latter is readily obtained by holding the electrode somewhat closer to the patient than when administering the effluve.

It may be applied either through the clothing, from which it is well to remove metal pins or jewelry, or directly to the skin. The longer the spark gap, the coarser and more penetrating the effluve, and such should be used when deep-seated conditions are being treated. For superficial lesions, as in skin diseases, the effluve should be fine, and hence a short spark gap used. It produces a feeling of warmth and as if minute solid particles were striking the skin. The stimulating effect of the effluve is greater the nearer it is to the body of the patient. Of course, it must be just short of the sparking distance. An electrode by which the distance between the end of the electrode and the patient's body

Fig. 194



High frequency brush or spray electrode.

can be maintained without variation is shown in Fig. 194. In administering the high frequency spray or brush discharge (p. 245), it is desirable and important to be able to regulate and vary the intensity to a nicety, from a barely perceptible effluve to a point just short of actual sparking. This is best accomplished by varying the distance intervening between patient and electrode. The design of the electrode is such that the distance from patient to discharge disk may be fixed and maintained automatically whenever desired.

The handle and central rod are of insulating material, and the rod passes through a metallic disk from which concentrically arranged pins

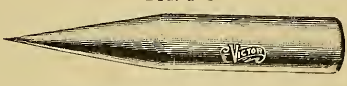
project. The disk can be easily and freely moved from end to end of the insulating rod, a thumb set-screw enabling the operator to fix it firmly at any point along the rod at will.

After determining the distance which it is desired to maintain between patient and electrode, the disk is placed the necessary distance from the

Fig. 195

Small metal ball electrode for high frequency current.

Fig. 196

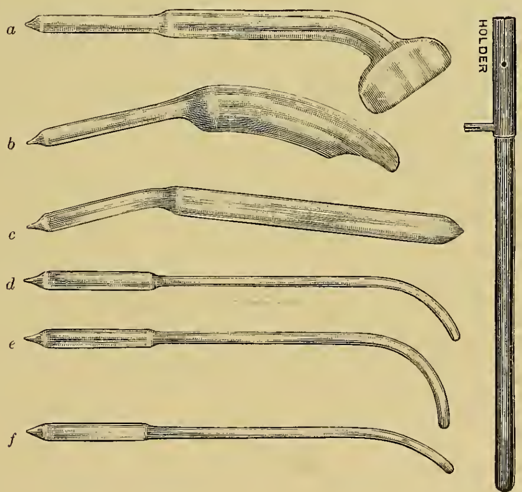


Pointed electrode for high frequency currents.

outer end of the insulating rod and the set-screw tightened; now, when the end of the rod is placed against the patient's body the desired result is attained, and it will be quite apparent the discharge disk cannot be accidentally shoved nearer to the body.

The spark caused by bringing the electrode close to the patient, if used, may be employed for similar purposes as the static spark (p. 227), but is believed to be not so contractile. Either a ball-tipped electrode

Fig. 197



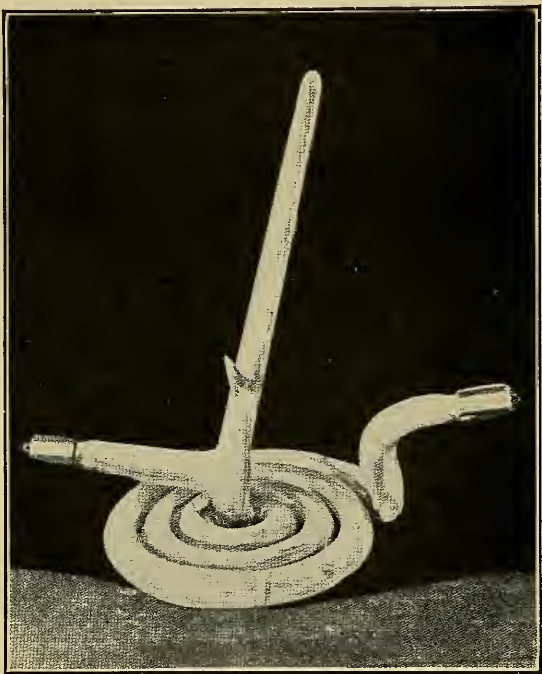
Vacuum electrodes: *a*, surface; *b*, uterine; *c*, rectal; *d*, throat; *e*, urethral; *f*, nasal.

(Fig. 195) or a pointed one (Fig. 196) may be employed for this purpose. When it is desired to use sparks the spark gap of the resonator should be wide open. To obtain a proper strength of current from the resonator, the apparatus must be adjusted to produce a condition of resonance (p. 101). This is done by increasing or decreasing the number

of turns of the D'Arsonval solenoid. This is accomplished with a movable contact (Fig. 165, *b*, and Fig. 79, *a*) which slides over the surface of the coil.

The glass vacuum electrodes are very convenient. They are made in different shapes, according to the part or cavity they are designed to treat. For the surface of the body Figs. 197, *a*, and 198 are usually employed. Types for special purposes are shown in Fig. 197. If it is desired to protect parts not being treated, the tubes may be insulated by making the electrode of two concentric tubes with an air space between. This prevents the escape of the current except at the end

Fig. 198



Large surface glass electrode.

of the electrode (Figs. 199 to 205). These are of advantage when the interior of a cavity is to be treated. Vacuum electrodes are inserted into an insulating handle, as shown in Fig. 206. The local effect may be increased by using a "condenser electrode." In this, instead of the low vacuum, there is an internal disk-shaped aluminum terminal, the space between which and the walls of the tube may contain either ordinary air, salt solution, or be exhausted to a vacuum (Fig. 207). As a matter of fact, all vacuum electrodes are condenser electrodes.

The usual method of application is to employ the ordinary type of

vacuum electrode (Fig. 197, *a*), which shows a red or purplish color when the current passes through it. This is introduced into a handle, as in

Fig. 199

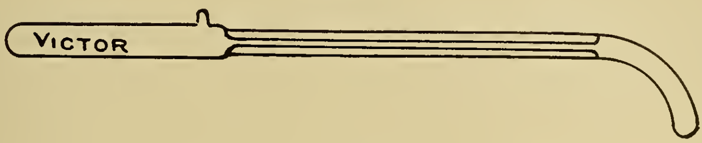


Fig. 200

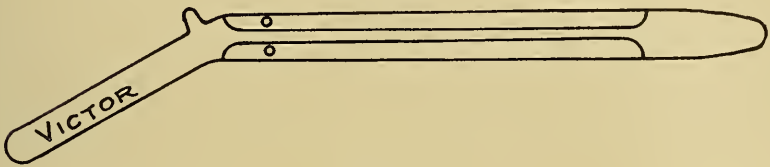


Fig. 201

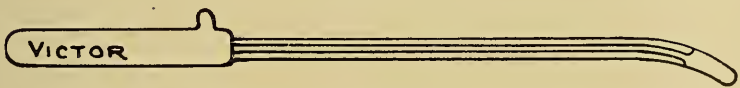


Fig. 202

Fig. 203

Fig. 204

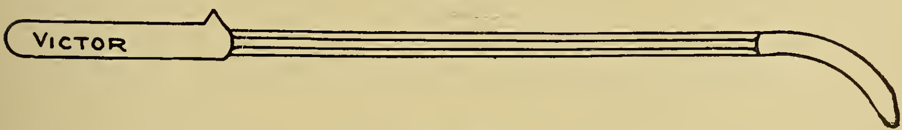
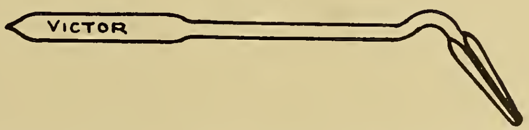


Fig. 205



Cavity electrodes, partly insulated, deliver current at point of application only. Fig. 199, for throat; Fig. 200, rectal; Fig. 201, nasal; Fig. 202, vaginal; Fig. 203, prostatic; Fig. 204, prostatic; Fig. 205, aural.

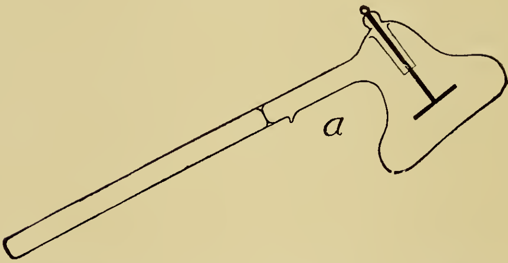
Fig. 206, and attached either to a resonator or one pole of the secondary of a Tesla coil. It should be applied to the part being treated before

the current is turned on. If the electrode is kept in close and immediate contact with the skin, merely a sensation of heat is experienced (Fig.

FIG. 206

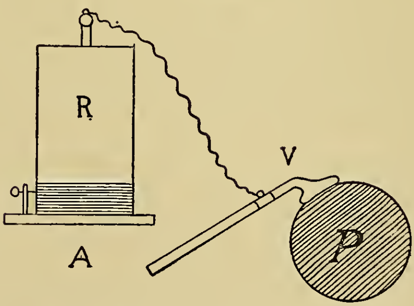
Universal handle and condenser electrode.

FIG. 207



Condenser electrode; "low red vacuum type." (Strong.)

FIG. 208



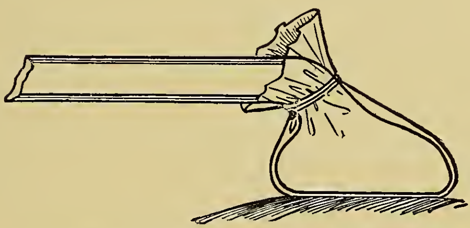
Monopolar direct technique. (Strong.)

208). If applied through one or more layers of clothing, a stinging, tingling feeling is experienced. The thicker the clothing the greater the pain. Burns may be so caused if the application is too strong.

A similar effect is produced[1] by keeping the electrode a little way from the surface, when a number of fine sparks will pass from the electrode to the patient. These also cause stinging and hyperemia, and if too strong may cause ulceration. These discharges produce ozone (p. 277).

A bipolar method may also be employed, which consists in connecting the patient with one end of the solenoid by means of an electrode (Fig. 210) and applying the current from the other end, as described above. For skin diseases, ulcers, and superficial inflammation, the electrode should be applied directly to the part for from five to ten minutes. When deep-seated conditions, as neuritis, inflamed joints, etc., are being treated, the stronger effect produced by making the application through the clothing should be employed. If the part is so situated that it cannot be applied through the clothing, the end of the electrode may be covered with some woollen fabric (Fig. 209). If a very strong influence is desired, a condenser electrode (Fig. 207) may be used.

Fig. 209



Vacuum electrode covered with chamois skin. (Strong.)

If the part being treated is of considerable extent, the electrode can be slid about so that the current reaches all desired parts, or such an electrode as shown in Fig. 198 may be used.

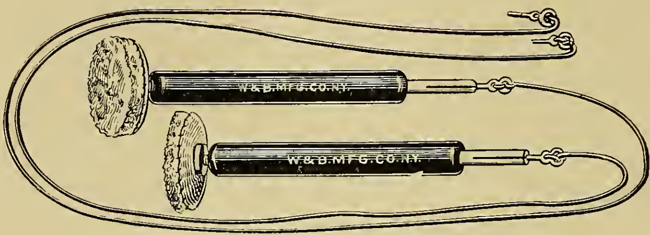
The vacuum electrode does not produce as great stimulation as the effluve unless it is applied over clothing or covered with cloth, as in Fig. 209. To relieve pain, a low vacuum tube is preferable. As these applications relieve stasis, promote phagocytosis, as they cause local hyperemia and cause the disappearance of exudates, they also relieve pain, and hence have sedative effects also.

Local stimulation can also be secured by using sponge or absorbent cotton covered electrodes (Fig. 210) attached to the D'Arsonval coil. If the interruptions are comparatively slow (200,000), muscle contractions and a sensation similar to those obtained from the sinusoidal current may be obtained. In addition, heat is produced, which gives a counterirritant effect. If the electrodes are moved about, as high as 500 milliamperes may be so administered; if they are kept

[1] This method produces a stronger effect than when the electrode is kept against the surface.

stationary, not more than 200 should be used; otherwise blistering of the skin may be caused. It is well to have a meter (Fig. 167) in the circuit. Such a current has been found useful in chronic constipation and conditions where deep-seated muscular contractions are desired, also wherever there is congestion and stasis as in neuritis. The patient may also be connected with one side of the oscillator (p. 74) while the

Fig. 210



Static electrodes, cord, handles, and sponges.

electrode connected to the other side is brought in contact with the patient. The electrode may consist of a sheet of block tin, which may be accurately moulded to the part. A small condenser is thus formed, the electrode and the patient forming the plates, and as this is charged by the oscillator, the spot to be treated becomes charged negatively and positively in rapid alternation.

SEDATION

Any of the forms of current just mentioned may be also used to allay pain and relieve muscular spasm. Under certain conditions one form may be more efficacious than another (p. 220), but in any case where one does not act as desired, it is well to try the other.

Faradic and Sinusoidal Currents.—To obtain the sedative influence of the faradic current, we use it very rapidly interrupted and preferably the current from the secondary coil. It is claimed by some that the finer the wire and greater the number of winds in the coil the more sedative is the current. The electrodes should be moist, one placed at some indifferent point and the other over the painful area or, if used to relieve spasm, over the affected muscles. The application should last several minutes and be as strong as the patient can comfortably bear.

The *sinusoidal current* is applied in a similar way and with a great number of alternations per second (14,000 to 16,000).

Galvanic Current.—The galvanic current may be applied either labile or stabile, with the anode always as the active electrode (see Electrotonus) and the kathode at some remote point (Fig. 172). In the treatment of a localized pain, as a neuralgia, the stabile method should be used, the anode (a small electrode) being placed over each of the painful spots

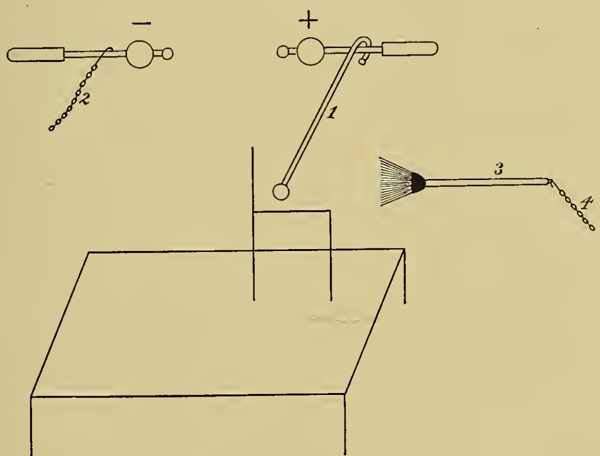
in turn. The current must be as strong as can be comfortably borne; the application to each tender point should last several minutes, and be made at least once daily, and oftener if possible. The current strength should be increased gradually to the desired strength and *decreased in strength gradually;* sudden interruptions of the circuit must be avoided. A solution of cocaine placed on the anode will increase the palliative effects of this method (see Phoresis).

In the treatment of diffuse pains, as in muscular rheumatism, the labile method may be employed. The same general principles just described also hold good when this method is used. A larger electrode may, however, be used.

For the relief of localized muscular spasm, the anode stabile over the affected muscles and their supplying nerves, as in the treatment of neuralgia, is the most useful plan.

The combined faradic and galvanic current (p. 221) has been much lauded by Rockwell for the relief of localized muscular spasms. It is applied by means of moist electrodes, as either current would be separately. The currents are combined in one circuit by an arrangement of switches (p. 123).

FIG. 211



1, shepherd's crook held by patient; 2, ground chain to water pipe; 3, wire brush electrode; 4, ground chain to gas pipe. (Snow.)

Static Current.—To obtain the local sedative effects of the static current either the static spray, breeze, brush discharge, static induced, or wave currents may be employed. Under some conditions sparks may also prove useful (pp. 124 and 231). The *spray* is administered as follows (Arnold Snow) (Fig. 211):

1. The poles of the machine are widely separated.
2. The patient on the insulated stool holds the shepherd's crook, connecting him to either side of the machine, preferably the positive.

3. If connected to the positive, the negative side is grounded, and *vice versa* (p. 211).

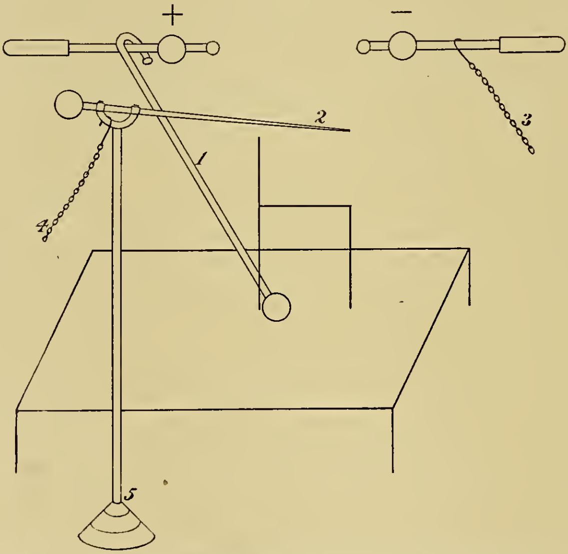
4. The operator then administers the breeze by a to-and-fro motion of either a brush (Fig. 192, *a*) or point electrode (Fig. 192, *e*). Care must be taken not to bring the electrode too close to the patient, as a painful spark may be discharged.

The connections for the *breeze* are shown in Fig. 212.

1. The patient is seated on the insulated stool and the poles of the machine widely separated.

2. The shepherd's crook extends from the positive pole either directly to the patient, as in Fig. 211, or to the insulated platform, and the other pole is grounded (Fig. 212).

FIG. 212



1, shepherd's crook; 2, point above patient's head; 3. ground chain to water pipe; 4, ground chain to gas pipe; 5, stand for holding point or crown electrode. (Snow.)

3. The stand is placed either with the point electrode near the part of the patient to be treated (Fig. 213) or the crown electrode over the head as indicated (Fig. 160).

4. A stronger effect is produced by connecting the electrode directly with the negative pole.

The breeze is sometimes termed the *souffle*. Its nature is described on page 20.

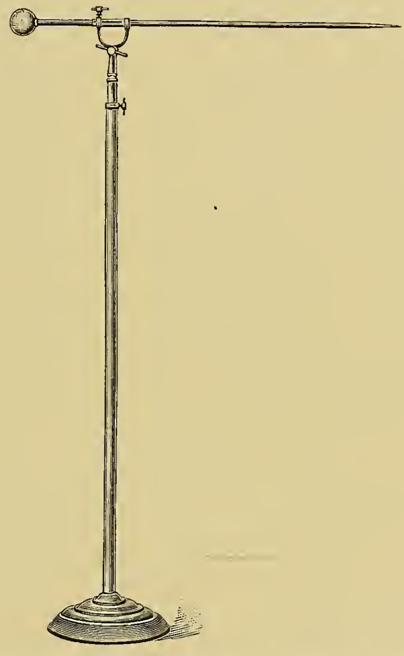
Similar precautions should be employed as directed in the administering of sparks (p. 229); in addition it is important that all metal pins and ornaments should be removed to avoid sparks (p. 212).

Rockwell and others claim that better sedative effects are obtained by attaching the electrode to the positive side of the machine instead

of the negative, while the patient is connected with the negative. In headache two pointed electrodes may be employed, one directing the breeze to the cervical spine and the other to the forehead.

By a *brush discharge* in electrotherapeutics is meant a discharge taking place between an insulated body connected with a static machine and an electrode of some resisting material, as wood (Snow). In other words, it is applied to a discharge which passes for a distance through a substance of very high resistance that may or may not have a metallic terminal from which the discharge is emitted. It must not be confused

Fig. 213



Adjustable stand for holding long-point electrode. (Snow.)

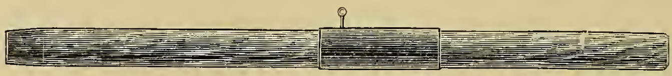
with a similar term used in electrophysics to indicate an electrical discharge from one terminal of a high potential apparatus, without regard to the substance of the conductor between the terminal and the course of the current (pp. 20 and 51).

The discharge is of a violet color, rich in ultraviolet, violet, and blue-violet rays. It also produces large quantities of ozone and nitrous oxide, the former of which may account for some of its effects.

To obtain it, a powerful static machine, the speed of which can be conveniently regulated, and wooden electrodes made of a wood that will absorb moisture, which should have a long handle with terminals of

various shapes, ball, point, etc., as shown in Figs. 214 to 217. Metal tips may also be attached to the wooden handle if more concentrated discharges are desired. It is essential that the wood be moist, and they may be dipped in water before using if they have become dry. A

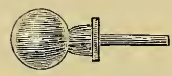
Fig. 214



Handle for ball electrodes.

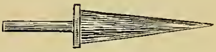
method of maintaining moisture has been devised by Dr. E. T. Nealey, as follows: Instead of wood sticks as handles, a glass tube with a small orifice is used. This is filled with a fluid of proper resistance for the size

Fig. 215



Electrode with wooden ball terminal. (Snow.)

Fig. 216



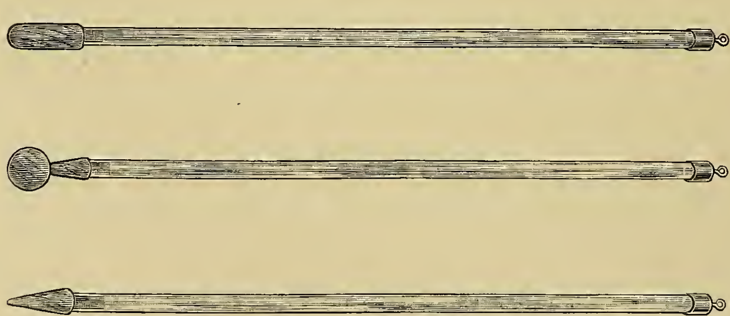
Electrode with wooden point terminal, for angles and clefts of body. (Snow.)

Fig. 217

Electrode with wooden terminal designed for placing test-tube over the wood. (Snow.)

of the machine with which they are to be used (the fluid is furnished with the electrodes). To one end of the tube is attached the wooden terminals, while at the other is a ring for the attachment of the grounding chain (Fig. 218).

Fig. 218

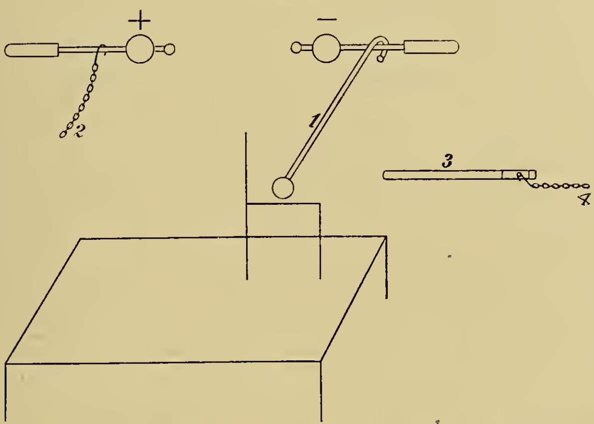


Electrode for brush discharge.

The patient must be thoroughly insulated and the platform is connected with one side of the machine, negative if a sedative and positive if an irritating effect is desired; the opposite side is grounded. The machine, with the discharging rods wide apart, is then started gradually and its speed increased according to the effect desired. The electrode

must be grounded to a separate ground from that of the machine by a chain which preferably should be insulated where attached to the electrode, and held at about 15 inches from the part to be treated (Fig. 219). De Kraft[1] advises that before starting the machine the electrode so grounded should be placed on the platform to avoid sparking in the machine; after this is started it is picked up. He also cautions against removing the electrode from the patient while the machine is running at high speed, as a disagreeable shock may be so caused; always stop the machine gradually. If it must be stopped suddenly, first short-circuit it by putting the electrode on the platform. If it is desired to place the patient's feet on a metal plate, see that the shoes are removed. Cotton, linen, or wet clothing lessens or abolishes the effect. It may be increased by placing one or two layers of silk or woollen cloth over the part to be treated. Care must be taken not to employ too many thicknesses, as they may catch fire; celluloid hairpins and buttons should be removed for the same reason. This modality is especially efficacious on hot, damp days, thereby differing from other forms of static modalities. While the machine is running slowly, the discharge is of a sputtering character; as its speed increases it becomes concentrated—the blue pencil flame. The sensation to the patient is as if hot sand were being thrown upon the skin. The electrode should be moved over the part being treated.

Fig. 219



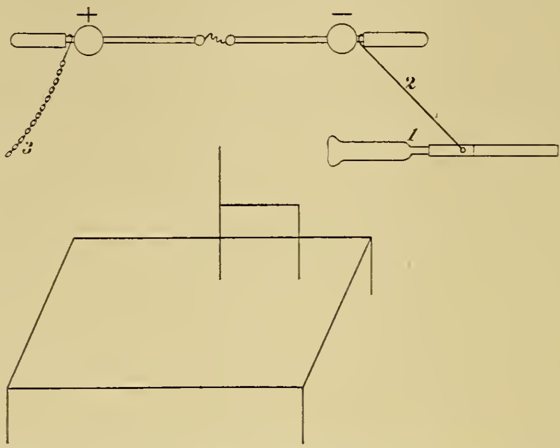
1, shepherd's crook held by patient; 2. ground chain to water pipe; 3, wooden electrode with metal sleeve; 4, ground chain to gas pipe. (Snow.)

When connected with the negative side, as has been said, the discharge is soothing, has possibly some antiseptic effect, dilates and contracts the bloodvessels, promotes absorption, and possibly effects metabolism. It has been found useful in sprains, neuritis, neuralgia, neurasthenia,

[1] Journal of Advanced Therapeutics, August, 1909, p. 367.

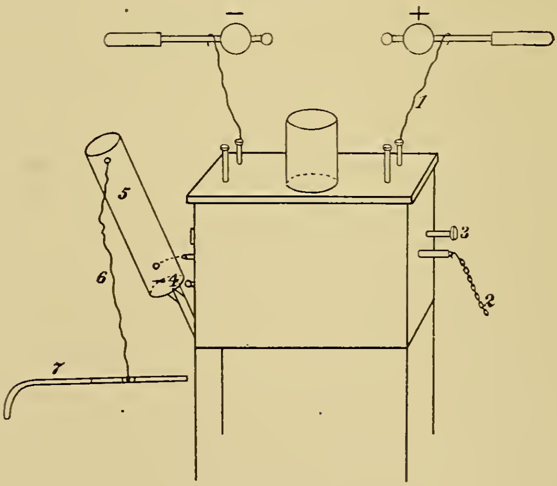
and insomnia. It has been claimed (De Kraft, *loc. cit.*) that the sputtering discharge will stimulate the healing of sluggish ulcers and abort boils before pus has formed.

FIG. 220



1, vacuum tube held by operator or patient; 2, connecting wire; 3, ground chain to water pipe. (Snow.)

FIG. 221



1, wires connecting the pole to the Leyden jar; 2, ground chain to water pipe; 3, spark-gap regulator for Leyden jars; 4, wire connecting solenoid with coil; 5, solenoid; 6, wire from solenoid to handle for vacuum tube or to a ball electrode or carbon point; 7, vacuum electrode. (Snow.)

The discharge when connected with the positive side is decidedly painful and irritating and is not much employed. Vacuum electrodes

may also be employed for similar purposes by attaching them to either side of the static machine (Fig. 220), or a resonator may be used (Fig. 221).

Static sparks (pp. 124, 227), by their power to promote absorption and equalize the circulation, may also be used to relieve pain, as in neuritis, sprains, etc.

The *wave current* (p. 258), the metal electrode being placed over the affected area, may also be employed in similar conditions.

High Frequency Currents.—The effluve derived from either the Tesla coil or resonator, or the current applied by means of vacuum electrodes (Fig. 197), is also of great service in relieving pain in many cases of chronic neuritis, inflamed and painful joints, muscular rheumatism, etc. (p. 139).

CHAPTER XIV

METHODS OF PRODUCING GENERAL ELECTRIFICATION

All forms of current may be utilized to influence nutrition and stimulate the different viscera, and hence exert tonic and eliminative effects. As a rule, either static or currents of high frequency are the most useful for this purpose.

FARADIC CURRENT

Procedure.—The procedure by which the faradic current is used for the above purposes is known as *general faradization.* It was first introduced by Beard and Rockwell in 1867. The following description of the method is based on that given by Rockwell:[1] The patient may be either in the sitting or recumbent position; if the former, he should be placed on either a stool or chair without a back, with his face toward the battery; the feet should be bare and placed on a large flat electrode (Figs. 110 and 146), which is connected with one pole of the battery. If it is not convenient to place the feet on the electrode, the patient may sit upon it. A large wet sponge, into which the conducting cord is introduced, may be used if the electrode is not at hand. If the recumbent position is necessary on account of inability of the patient, from weakness or paralysis, to sit up, the electrode may be placed against the feet and held in place by means of a pillow or bandage, while if the large sponge is used it may be placed between the feet, which are held together by means of a bandage. When the application is being made to the legs it is well, if possible, for the patient to stand. An ordinary electrode, one or two inches in diameter, covered with cotton well wetted, is used to apply to the patient. In very sensitive regions the hand of the operator is a good electrode (p. 224). The operator should stand near the battery and a bowl of water should be close by. The current used should be rapidly interrupted and from the secondary coil.

As the head and face are very sensitive, and mild currents are frequently quite painful, it is often well to omit treating these parts; if they are, the hand kept well wetted, used in the manner described above, is the preferable method. This should be pressed over the forehead and top of the head, where the hair should be also wetted, and the current allowed to pass steadily for about two minutes in each situation, the current, of course, being merely strong enough to be perceived. The neck is passed to where an ordinary electrode is employed, which should

[1] Medical and Surgical Electricity, 1907, p. 312 et seq.

be firmly pressed in on each side of the neck in the region of the sixth and seventh cervical vertebræ, in order to influence the cervical sympathetic, phrenic, and pneumogastric nerves, and other structures there. A stronger current may and should be used in this situation. The arms are next treated by passing the electrode labile with a current sufficiently strong to produce muscular contractions. The hand may be used instead of the electrode. The electrode should next be passed up and down the spinal column a number of times, and over the muscles of the back; a strong current is necessary and can be used in this region. The chest is then treated in a similar manner, using a weak current over the ribs. The stomach and solar plexus are reached by placing either the electrode or hand under the sternum and pressing as far back as possible. The abdominal muscles and bowels are next treated by passing the electrode over the abdomen; if constipation exists, the current should be used so as to produce clonic contractions of the abdominal muscles (p. 317). Corpulent people require a stronger current than thin ones. If the feet are placed on an electrode, the legs will be sufficiently influenced from that, and they need not be further treated, unless paralysis exists, when they may be treated as the arms. The length of the treatment should range from five to thirty minutes, according to the temperament of the patient. It is well to begin with treatments of short duration and mild currents, gradually increasing in duration and strength. The following table based on a treatment of fifteen minutes' duration shows the proportionate length of time to be expended on each part. These should, of course, be increased as the length of treatment is increased.

To the head	1 minute
To the neck, sympathetic and cervical spine	4 minutes
To the arms	2 minutes
To the back	3 minutes
To the abdomen	3 minutes
To the legs	2 minutes

The frequency with which this should be administered depends upon the condition and susceptibility of the patient. Every other day is the average; very weak and nervous patients less than this, and this should be continued from four to eight weeks.

Effects.—According to Rockwell, the permanent tonic influence of this treatment is frequently quite marked. The effects have been divided by him into three classes:

1. Those which are experienced during or immediately after treatment, viz., primary or stimulating effects.

2. Those which are experienced one or two days after the treatment, viz., secondary or reactive effects.

3. Those which remain as a permanent result of treatment, viz., permanent or tonic effects.

The primary effects are experienced by the majority of patients. They consist of a greater or less feeling of well-being, exhilaration,

increased cardiac action, and a slight rise of temperature, and in some instances a desire for sleep. Those suffering from the various vague pains peculiar to neurasthenia are frequently relieved for a greater or less period of time.

Symptoms such as headache, malaise, vertigo, and faintness following the treatment indicate a too long and strong application.

The secondary effects do not occur in the majority of patients, and then only after the first few treatments. They consist of muscular soreness and fatigue and nervousness. Their occurrence may be avoided by making the first few treatments brief in duration and weak in strength, increasing gradually to the usual limits.

The permanent effects expected are increased ability to sleep, increased appetite and improved digestion, relief of constipation, improved circulation, relief of nervousness and mental depression, and increased strength.

Of course, it is not to be expected that such results occur in all cases, and it is well often to combine other proper therapeutic resources with our electrical treatment.

A modification of this procedure is recommended by Weir Mitchell as part of his so-called "Rest Cure." His plan is to go over all the muscles with the slowly interrupted current, causing a few contractions of each, paying special attention to those of the abdomen. This is followed by placing one electrode at the nape of the neck and the other, either the large plate or sponge, as described on page 250, at the feet. The rapidly interrupted current, strong enough to produce not uncomfortable tingling sensations, is then allowed to pass for fifteen to twenty minutes. It is customary to omit the treatment in women during the menstrual period.

GALVANIC CURRENT

One of two procedures may be used to produce general electrification by the galvanic current. They are termed respectively *General Galvanization* and *Central Galvanization.*

General Galvanization.—In general galvanization the galvanic current is employed instead of the faradic, the kathode being placed at the feet and the anode used to pass over the body. The various steps of the procedure are similar to those employed in general faradization, and it is employed to attain the same results. Faradization is preferable. If the galvanic current is used, care must be taken to employ a weak current on the head and neck and in the cardiac region.

Central Galvanization.—Central galvanization was introduced by Beard and Rockwell in 1871.[1] It has been employed with success in hysteria, neurasthenia, and dyspepsia. The object of the procedure is

[1] A. D. Rockwell, Medical and Surgical Electricity, 1907, p. 196.

to bring the entire nervous system under the action of the galvanic current. One pole, usually the kathode, which should be a large electrode, is placed on the epigastrium; the anode, a smaller electrode, is placed first on the forehead for about one minute, then slid to the top of the head, the hair being well wetted, where it is allowed to remain for from one to two minutes. The currents in these situations should be just strong enough to cause a metallic taste, usually about three to five milliamperes. Special care must be here taken not to open or close the circuit suddenly. The electrode is next passed for from one to five minutes up and down the inner borders of each sterno-mastoid muscle. Next, the spinal cord is treated by passing the electrode up and down its length for from three to six minutes. Special attention should be paid to the cervical region. The current in this situation should be much stronger, for instance from ten to thirty milliamperes. The applications are all labile, the current being increased and decreased gradually, shocks being avoided, and should be repeated with the same frequency as recommended for general faradization. This method is enthusiastically recommended by Rockwell for all functional nervous diseases, he preferring it to general faradization excepting when there is marked muscular weakness, when the latter is preferred. While there is no doubt that it is in some instances of benefit in this class of cases, the writer has not seen the marked results claimed for it by its introducers. It is doubtful if a great amount of electricity can be made to reach the brain and cord (p. 129).

HYDRO-ELECTRIC METHODS

These comprise two, *i. e.*, the *electric bath* and the *electric douche;* the latter may also be used to produce local effects.

Electric Bath.—The requirements for administering electric baths, as given by Hedley,[1] are as follows:

1. A constant current supply either in the shape of a battery with a low resistance, which will work up to a powerful current strength through the estimated R,[2] or from an electric light circuit, which will have to be safeguarded by shunts and appropriate resistances in addition to a reliable "cut out."

2. A means of opening and closing the circuit and regulating strength by easy gradation, so as to avoid pain or shock, *i. e.*, "current collector" or rheostat, or in dynamo circuits an adjustable rheostat or a sliding shunt.

3. A milliamperemeter, registering up to 500.

4. A powerful induction coil for faradic bath, or a supply from an alternating dynamo (sinusoidal current).

[1] Transactions of the American Electrotherapeutic Association, 1894, p. 214.

[2] According to Lawrence (ibid., p. 144), such a battery should consist of 40 to 60 cells having an E. M. F. of not less than one volt per cell, such as a three-pint or two-quart Leclanché cell.

5. Some means of suddenly reversing the current (current reverser or pole changer), as well as an arrangement for throwing the two currents together for combined use ("current combiner" or "De Watteville key," p. 123).

6. As an adjunct but not an actual necessity may be mentioned a voltmeter, useful for occasionally determining the E. M. F. of the battery or of any particular cell, and for other purposes. A bath tub, best made of either wood (oak) or porcelain, which must be carefully insulated, both from conducting wires and waste pipe, the latter being insulated from earth by a short length of rubber tubing let in near the bath.

The tub should be four feet ten inches long, and two feet six inches at the greatest width, which is about two inches nearer the head than foot. Height at head, one foot eleven inches; height at foot, one foot five inches. There are five fixed electrodes of bright metal covered only by a light removable open wooden framework. Their size is as follows:

Cervical, 28 × 29 cm.
Lumbar, 24 × 17 cm.
Lateral (2) 26.5 × 18 cm.
Gluteal (circular), 30 cm. (diameter).
Terminal (foot) 22 × 38 cm.

In addition to these there is an electrode for monopolar purposes, consisting of a removable metal rod, one inch in diameter, covered with wash leather. This is fixed across the widest part of the bath, and can be conveniently grasped by the hands. These electrodes are connected by carefully insulated wires with seven terminals, and these in turn lead to a switchboard, so arranged that by the insertion of plugs any electrode can be brought into action either as anode or cathode. The switchboard is connected to the battery, coil, or other source of supply.

In addition, the so-called "paddle electrode" is very useful, as by means of a long insulated handle it can be applied to the vicinity of any part of the body upon which it may be desired to concentrate the current.

It is preferable, according to Lawrence (*loc. cit.*), that the water taps be either made of some insulating material or else so situated that the patient cannot touch them. Shocks have been caused by so doing. The bath may be galvanic or faradic, monopolar or dipolar (Fig. 222).

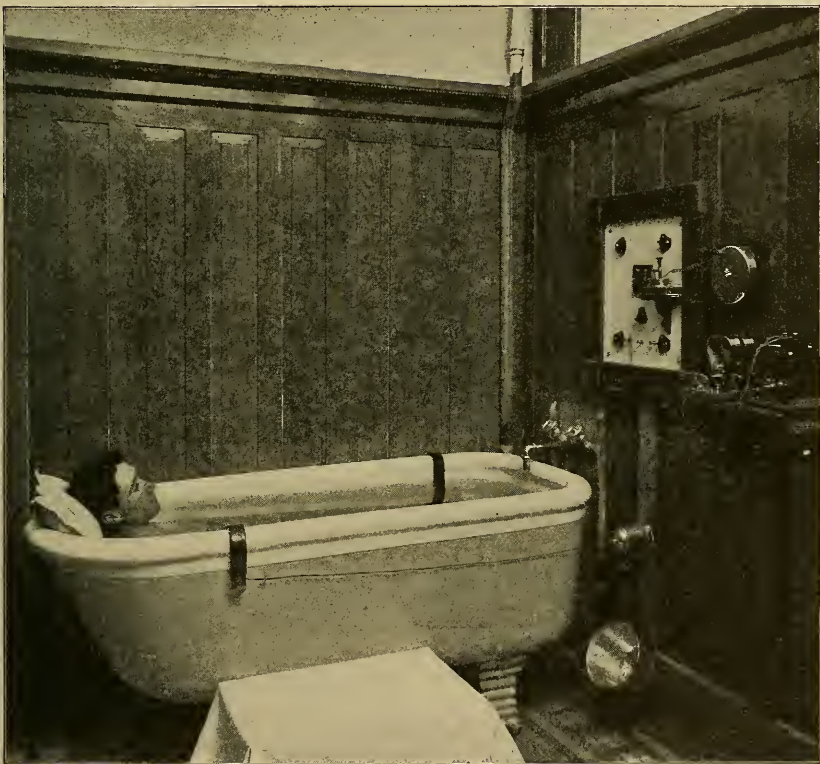
In the *monopolar bath* only one electrode is submerged, while the patient either grasps the rod electrode with the hands or the other electrode is placed upon some part of the body not submerged. By this latter method the current can be concentrated at some particular point. If necessary, this form of bath can be administered in an ordinary wooden wash tub, as it is not necessary for the entire body to be immersed.

The *dipolar bath* consists of a complete immersion of the body in the

water, two of the electrodes (p. 254), according to the direction in which it is desired to pass the current, being connected with the source of electrical supply.

For the galvanic bath a current strength of from 50 to 280 milliamperes is required. Hedley begins with 50, the current being gradually turned on; this is continued for five minutes, then gradually made stronger, the first bath lasting for from eight to ten minutes. In a couple of days another bath with a stronger current and of somewhat longer duration

Fig. 222

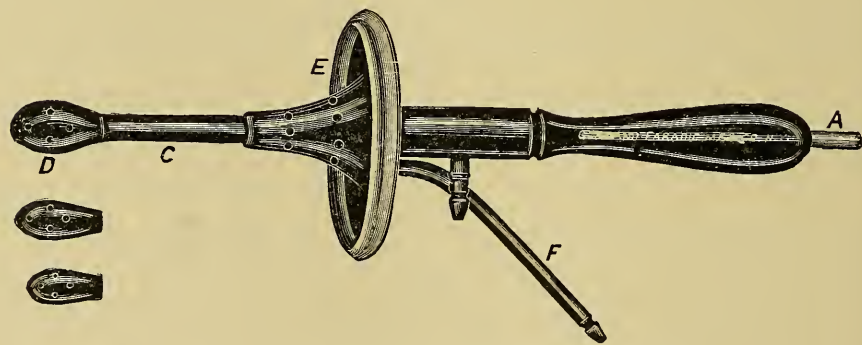


Hydro-electric bath. (Kellogg.)

is given. In another day or two a third; then, if the baths agree with the patient, a series of six are given on successive days, then two or three on alternate days, an average course of treatment extending over three weeks and consisting of twelve baths. Hedley thinks that only about 25 per cent. of the current enters the patient's body. In giving the galvanic bath care must be taken that the patient does not come in direct contact with the electrodes. The current must be gradually decreased before immerging from the bath.

The *faradic* and *sinusoidal baths* are given in the same way, substituting the faradic coil or alternating current from the dynamo as a source of electrical supply. The current should be gradually increased in strength until tingling is caused. The faradic is usually preferred to the galvanic, the chief advantage of the latter being that drugs may be introduced into the body by phoresis (p. 114). The patient should rest a while after the bath. The baths are said to act as a tonic, as shown by an increase of appetite, digestion, physical and psychic powers. The faradic current for this purpose being preferably used. The water should be at a temperature of 92° to 95° F. for five to six minutes, and then reduced to 80°, followed by brisk rubbing. Lehr states that the excretion of uric acid may be increased by the dipolar method. Sedative effects may also be caused and insomnia relieved. The galvanic current is preferable for this purpose. The temperature being from 92° to 97° F., and the bath lasting from twelve to fifteen minutes. Kellogg advises that the anode be at the head of the patient. In general it may be said that the strength of current used, the duration of the bath, and the direction of the current depend on the susceptibilities of the patient, the effect desired, and the particular part of the body which it is desired to influence.

Fig. 223



Electrode for vaginal hydro-electric applications. (Cleaves.)

All wounds, abrasions of the skin, and ulcerated surfaces must be protected from the action of the current by some insulating material. For feeble persons an arrangement such as is used for typhoid patients can be utilized. If the patient presents any disturbance of pain or temperature sense, care must be taken not to use too strong a current, as such a patient may not be able to indicate by his sensations when such is the case.

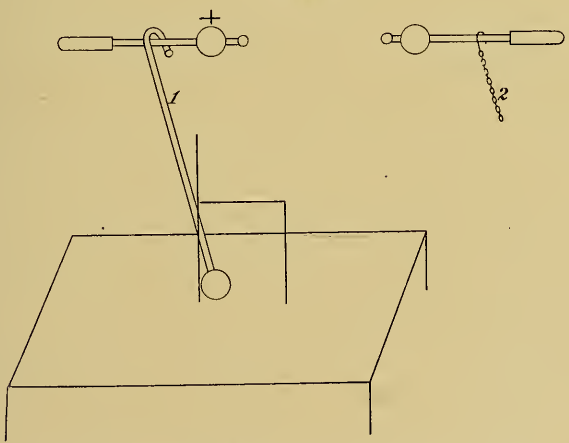
Electric Douche.—The *electric douche* is described by Hedley (*Therapeutic Electricity*) as follows: "The apparatus consists of a short length of flexible rubber tubing, having an inside conducting wire, one end of which is brought out and connected to a terminal about two inches

from the brass union which joins on to the supply pipes. The two inches of rubber tubing thus interposed between the metal pipes and the conducting wire act as effective insulation at this end of the arrangement. The other end of the internal wire is soldered to the inside of the metal screw, to which different nozzles may be attached." One pole of the battery is connected with the conducting wire inside the rubber tube, the other is placed in the bath in which the patient stands. If the galvanic current is used, an E. M. F. of 50 to 60 volts must be employed. If the faradic current is used, a current strong enough to produce tingling is required. Hedley claims excellent results for this method in old paralyses, neurasthenia, and anesthesia. Cleaves[1] has utilized this method to apply electricity to the cavities of the body, such as the rectum, urethra, vagina, stomach, etc., and has devised special electrodes for this purpose. A type is shown in Fig. 223.

STATIC ELECTRICITY

To produce general effects without local action by means of the static current, the so-called static bath, static insulation, or static electrification may be employed. This is also an excellent method to use at first, even when more vigorous measures are indicated, if the patient

Fig. 224



1, shepherd's crook; 2, ground chain to water pipe. (Snow.)

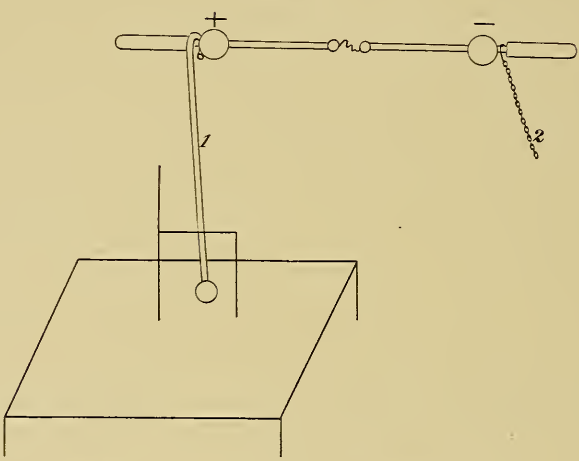
is nervous or fearful of the treatment. To administer this, place the patient upon the insulated stool and connect him directly with either the positive or negative side of the machine (pp. 130 and 258), ground the side not connected with the patient, widely separate

[1] Transactions of the American Electrotherapeutic Association, 1894, p. 173.

the discharging rods, then start the machine (Fig. 224). A pleasant tingling and glow, with increase of perspiration, is experienced by the patient. The static breeze may be combined with this by placing the stand electrode (Fig. 213) with the point directed to the part of the patient where its use is indicated.

Interrupted electrification or *potential alternation* may also be employed, the connections being made as above, but instead of the discharging rods being widely separated they are brought close enough together for a spark to pass (spark gap). This produces an oscillatory action upon the tissues of the patient. The greater the spark gap, the stronger the effect (Fig. 225). Some consider that negative electri-

Fig. 225



1, shepherd's crook; 2, ground chain to water pipe. (Snow.)

fication (connection with the negative pole) is sedative, while positive electrification is stimulating; as a matter of fact, some patients do better when connected with one, and some with the other. Experience alone will determine which.

Nervous excitement is calmed and sleep promoted when employed as a sedative. The tonic influence is evidenced by increased appetite, lessening of fatigue, and improved nutrition. The treatment is indicated in neurasthenia and kindred neuroses.

General sedative effects, which if the application is long continued become stimulating, may be obtained by rubbing either an uninsulated ball or roller electrode over the patient's clothes, as described on p. 230. This method applied to the legs may be used as a derivative in cases of spinal congestion from any cause.

An effective method of obtaining general and also local effects is the employment of the *wave current* (p. 101). Its various physiological effects are detailed on p. 135.

Application (see also page 261).—For its application the following directions are given by Snow,[1] as the results of considerable experience with it.

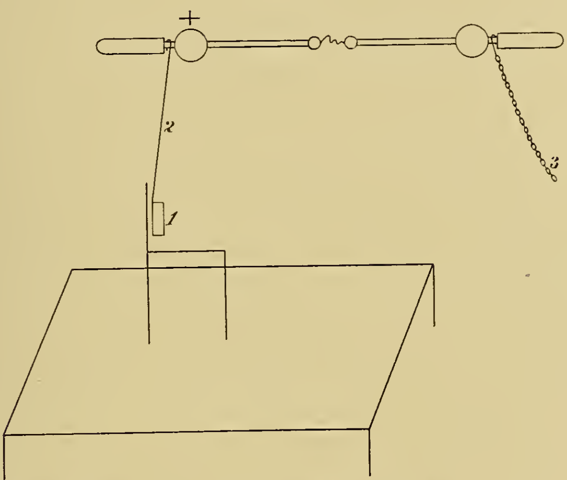
1. Ground one pole of the machine[2] to a gas or water pipe. A good ground is imperative, and the matter of polarity, so far as known, is immaterial.

2. Always treat the patient on the insulated platform.

3. Always employ metal electrodes (lead or block tin are best, because pliable), and see that no material is between the electrode and the patient's skin.

4. Connect the patient by one cord—or more if several joints or parts are being treated at one time—to the side of the machine not grounded.

Fig. 226



1, metal electrode on patient; 2, connecting wire; 3, ground chain to water pipe. (Snow.)

5. Close or nearly close the prime conductors; start the machine.

6. Gradually separate the prime conductors until there is commencing discomfort, evidenced by either muscular contraction, a burning sensation, which will disappear as soon as the skin becomes moist, or pain if the electrode is applied over an inflamed nerve. After short intervals the spark gap may be increased from time to time to get the best results.

7. In treating neuritis, do not make the electrode too large, or the current will be too much diffused to produce the best result.

8. Allow no object that would draw off the current to come near the platform, and be careful that no one touches the patient, for obvious reasons.

To obtain a general tonic influence, the best form of electrode is a long sheet of either lead or block tin, about one inch in width and twelve

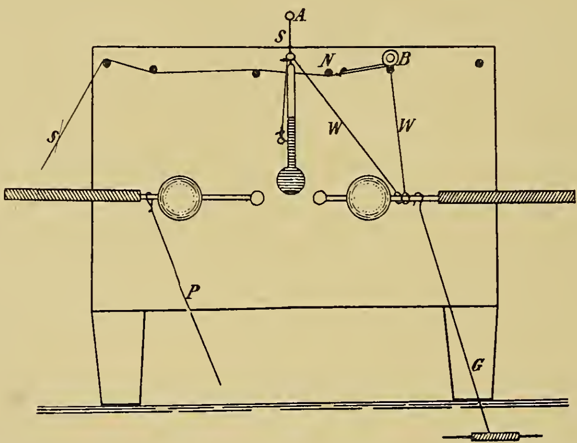
[1] Medical Record, March 3, 1900, p. 359.

[2] Static machine.

to fourteen inches in length. This should be placed along the spine. When a local influence is desired, smaller electrodes of similar material applied to the part should be used. Fig. 226 shows the connections when only one electrode is employed.

Various schemes have been devised to cause strong but slow interruptions of this current. That recently published by Pfahler[1] seems to be one of the best. It prevents tetanic contractions of the muscles, which tire them and cause pain. It consists in attaching an ordinary steel tape to the binding rod screw head. This is carried by a silk cord over the other posts at the outer edge of the case, and thereby easily adjusted at the opposite edge of the machine. The steel tape should be brought to within about one inch of the neutralizing rod. The spring pulls it back when the cord is relaxed. A thin wire is carried down to the grounded side and hooked over the rod. A ball electrode (Fig. 181) is

Fig. 227



Pendulum interrupter for the static wave current. (Pfahler.) *A*, support; *B*, binding post; *C*, steel spring tape; *G*, ground; *N*, neutral comb; *P*, patient; *S*, silk cord; *W*, wire.

suspended midway between the two poles of the static machine. This is done by placing a screw eye in the top of the handle and hanging it on a hook from a short cord, which will eliminate all friction, the cord being stationary and providing sufficient insulation. This can hang from an adjustable cord if desired, which will aid in regulating the length of the spark. The ball should hang so that it will just swing past the ball on the rod of the opposite pole without striking when the proper length of spark is being obtained.

A very fine wire should then be carried from the grounded pole up through the screw eye in the handle of the ball electrode and down to the metallic ring attachment.

The connections with the patient are made as usual, then the machine

[1] Journal of Advanced Therapeutics, December, 1910, p. 583.

and pendulum are started. Gradually the pendulum will swing in an ellipse and a series of sparks will vary from long to short, and then long as the ball swings past the opposite pole. Following this there is an equal period of complete relaxation. The interruptions will be about sixty per minute. The connections are shown in Fig. 227.

Effects.—According to Snow,[1] powerful tonic effects are produced by this current (p. 135). The local effects (p. 135) depend upon several conditions:

1. The size of the electrode.
2. The length of the spark gap (the measure of electromotive force).
3. The nature of the ground connected to the grounded pole. (During application to sensitive areas, as the forehead, eye, ear, nose, and throat, it is best to operate without the pole being grounded at all; but in all other cases have best grounded connection obtainable.)
4. Upon the rapidity of alternation and voltage in relation to parts treated (large muscles require greater voltage and small ones less) will depend whether rhythmical contractions, physiological tetanus, or sedation is produced.
5. Polarity, so far as has been discovered, does not affect the result in the employment of the wave current. Applications of strong currents for one-half hour or more may be used to advantage in well-developed patients. Mild currents (from one inch spark gap) for fifteen minutes are sufficient for weak and debilitated subjects. This period of time and strength of current may be increased if well borne until sittings of from one-half hour to two hours' duration and a spark gap of one to four inches may be given daily. A sense of fatigue indicates too active a treatment. Fat persons require a stronger current and longer sittings than thin ones. This current may be used in all cases where a tonic is indicated and it is desired to influence metabolism, for instance, in neurasthenia, rheumatism and gout, anemia, insomnia, uric acid diathesis, chronic nephritis, etc. They may also be used as muscle stimulants, to relieve pain, and if very strong, to produce fatigue and consequent relaxation of muscles in states of spasm.

The static current may also be employed to administer treatment by autocondensation and autoconduction (p. 265). Pfahler states that much better general effects are obtained from a specially powerful static machine run at very high speed than by any other method. He uses one of twelve plates made by the Baker Electrical Company.

CURRENTS OF HIGH FREQUENCY

Application.—To obtain the general effects of the high frequency current (p. 135), the D'Arsonval current (p. 99) is preferably employed. It may be administered in several different ways.

[1] Transactions of the American Electrotherapeutic Association, 1900, p 276.

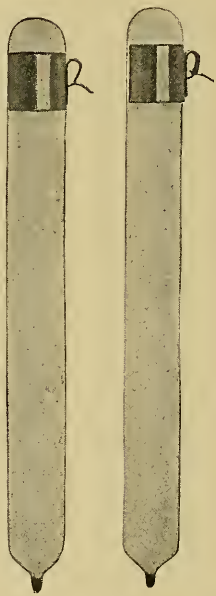
1. *The Direct Application or Application by Derivation.*—This is the simplest method and consists in connecting the patient directly to the opposite ends of the solenoid by suitable electrodes, either Fig. 228 or vacuum electrodes, Fig. 229.

Fig. 74 shows the connections at *A* and *B*. A branch circuit is thus formed through which a current passes of the same frequency as the main discharge. The contact between the electrode and the skin should be perfect, else disagreeable sparks will pass, and small ulcers may be caused. If the *stabile method* is used the electrodes may consist of plates of block tin which may be accurately moulded to the parts.

Fig. 228

Metal electrodes for treatment by derivation.

Fig. 229



Vacuum electrodes for treatment by derivation.

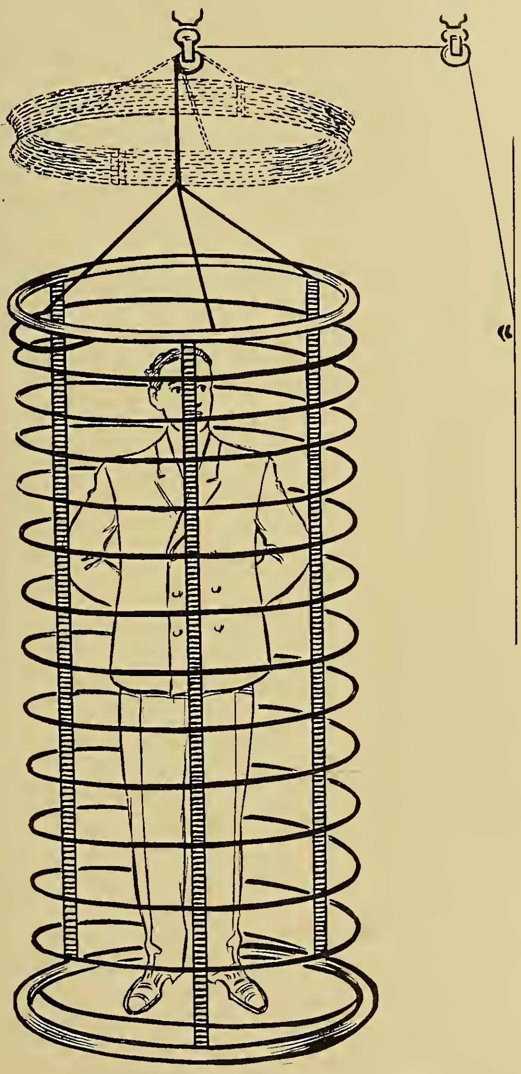
They may, if desired, be covered with wet flannel, or one electrode (Fig. 228) may be held in the hand, while the tin plate is placed where desired. The seances should last from five to ten minutes and neither sparks or muscular contractions should be caused.

2. *Autoconduction.*—In this method the patient is surrounded by a solenoid which is connected with the apparatus, but he is not in direct contact with it (Fig. 230). As the currents pass through the solenoid, a similar current is induced in the body of the patient. The cage must be large enough to cover the entire body, and may be arranged so that the patient can stand up or lie down. Powerful currents are made to pass through the body by this method, so that if the patient holds

in each hand the terminal wires of an incandescent lamp, it will be lighted.

3. *Autocondensation.*—When so employed the patient constitutes one armature of a condenser, while the other consists of a large sheet of

Fig. 230



Cage solenoid for autoconduction. (Allen.)

metal in his vicinity. This is most conveniently arranged by means of a couch (Fig. 231), on which the patient lies, being separated from the metal sheet by an insulating cushion filled with rubber waste, while he holds in his hands metal electrodes connected with one end of the

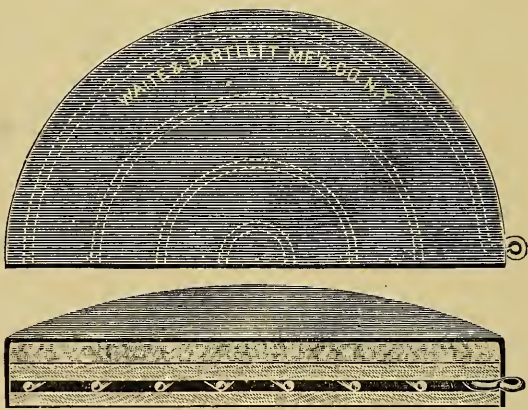
solenoid; the metal plate is connected with the other (Fig. 231). By this means, 400 or 500 milliamperes can be passed through the body. A more convenient form of chair is that devised by Piffard, and shown in Figs. 232 and 233.

Fig. 231

Diagram of autocondensation.

A *monopolar method* can be used in which the patient is connected with only one end of the solenoid. Similar results can be obtained by the employment of the large electrode devised by the Clapp-Eastham Company, of Boston. It is made on the same principle as the cushion of the couch above described, but an ordinary chair can be used.

Fig. 232

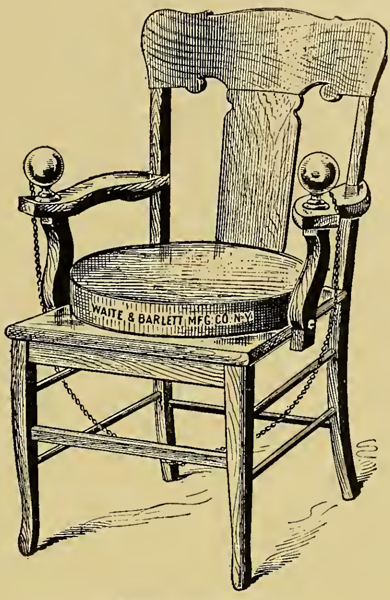


Piffard's cushion-spiral for D'Arsonval autocondensation current.

If the static machine is employed for autocondensation, connections can be made either as in Fig. 234 or, if a resonator is employed, as in Fig. 235. If the first method is used the discharging rods should be but very slightly separated at first; this may be increased according to the effect desired.

For autoconduction with a static machine, the connections are as in Fig. 236. An autocondensation couch is employed in this method,

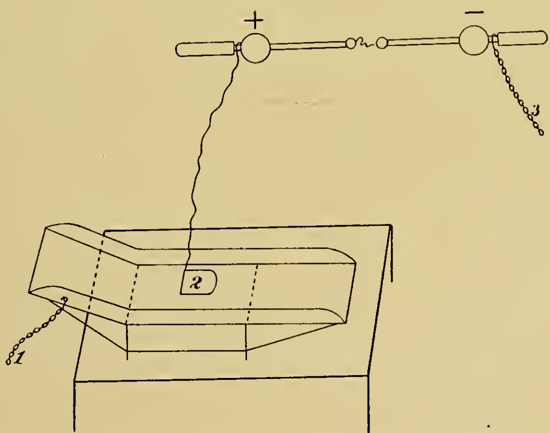
FIG. 233



Chair for Piffard's cushion-spiral.

which is connected with the positive side of the machine, while a half cage is suspended above him.

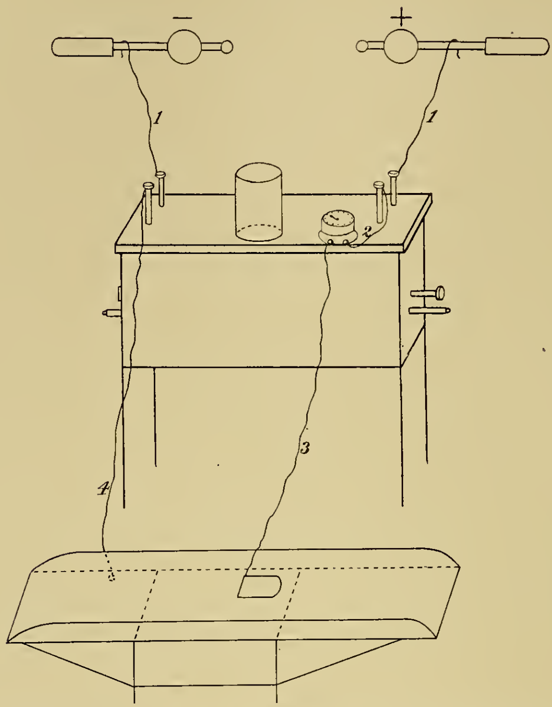
FIG. 234



1, ground chain from metal plate under felt cushion to gas pipe; 2, abdominal electrode on patient; 3, ground chain to water pipe. (Snow.)

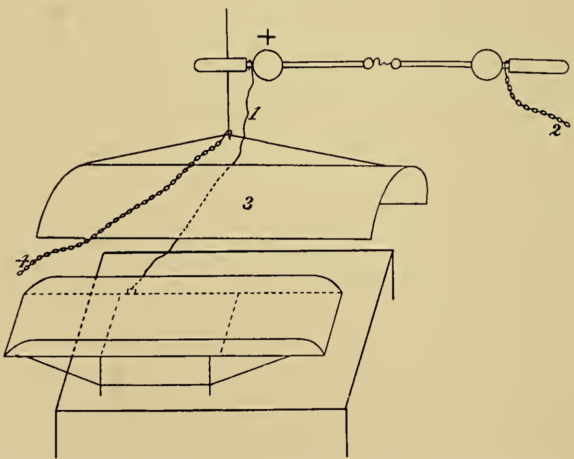
Snow believes the wave current to be superior to either of these methods.

FIG. 235



1, wires from poles of static to Leyden jar; 2, wire from D'Arsonval attachment to resonator to milliamperemeter; 3, wire from milliamperemeter to metal electrode on patient's abdomen; 4, wire from D'Arsonval attachment of resonator to metal plate under cushion. (Snow.)

FIG. 236



1, wire connecting metal plate beneath felt cushion with the positive pole; 2, ground chain to water pipe; 3, suspended half cage; 4, ground chain from half cage to gas pipe. (Snow.)

SECTION V

METHODS OF OBTAINING GENERAL AND LOCAL EFFECTS BY THE INDIRECT ACTION OF ELECTRICITY

CHAPTER XV

ELECTROLYSIS AND FULGURATION

Electrolysis.—As has been shown on page 49, this phenomenon plays a prominent part in the direct action of certain electric modalities, especially the constant current. In this chapter are described methods of employing it to obtain other results not dependent upon the action of the current within the living body.

Elsewhere (pp. 113 and 114) are detailed the manner in which it influences the tissues of the body and enables the constant current to promote absorption and increase nutrition of tissues. Here are stated the methods of obtaining results due to chemical effects produced at the poles by which destruction of tissue may be caused, and hemorrhage produced or checked. The action of each pole is given on pages 113 and 114. Its various fields of usefulness and methods of application in special cases are described in Section VI.

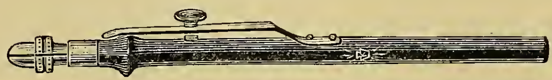
Apparatus.—The necessary apparatus consists of a source of supply of the galvanic current (Figs. 103 and 104); a milliamperemeter (Fig. 46) if possible; needles of various sizes, made of either gold, platinum, iridoplatinum, or steel; when strong currents are to be employed, and it is not desired to injure overlying tissues, these should be insulated to within a short distance of their points by a coating of either shellac or hard rubber (Fig. 334, *B*); a needle holder to hold one needle (Fig. 237) and one to hold a number (Fig. 238); plate electrodes of various sizes; other special electrodes may be required for special objects which are described under their respective headings, as stricture, uterine diseases, etc.

When it is desired to destroy abnormal growths or produce bleeding, the kathode or negative is employed as the active pole (p. 114); to cause coagulation of the blood or other fluid, a cautery action, or astringent

effect, the anode or positive is used as the active pole (p. 113). As a rule, when using the anode as the active pole the electrode should be of some non-corroding material, as gold or platinum; when using the negative pole this is not so important. In some cases, however, it is desired to obtain the action of products produced by the decomposition of the needle, in which case the anode may consist of copper or zinc, pure or amalgamated (pp. 390 and 391).

When only one pole is used as the active pole, the other pole attached to a plate electrode in size in proportion to the strength of the current (p. 194) should be placed at an indifferent point, *i. e.*, held either in the hand, on the thigh, or on the abdomen, as the case may require. In destroying large growths both poles may be made active.

Fig. 237



Interrupting electrolysis needle holder.

The current strength required varies from a few milliamperes, as in the case of superfluous hairs, to several hundred milliamperes, in uterine fibroids and malignant growths (p. 393).

When using the anode it will be found that, owing to the coagulation and contraction of the tissues produced by it, force is required to withdraw the needle. This can be obviated by reversing the poles so that it becomes the kathode for a few seconds, when it can be easily withdrawn.

Fig. 238

Multiple needle holder.

If strong currents (more than two or three milliamperes) are used, the current must be increased and decreased gradually by means of an appropriate rheostat (Fig. 105).

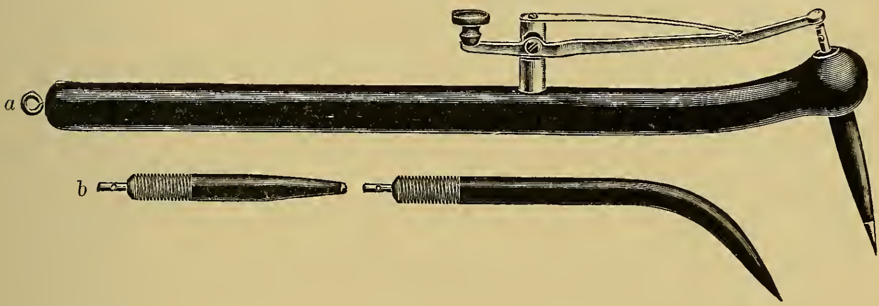
Fulguration.—Small growths also may be destroyed by the action of a stream of fine sparks from either static or high frequency apparatus. This has been termed "fulguration." A metallic pointed electrode, as in Fig. 239, is attached to one terminal either of the Tesla secondary coil or the Oudin resonator, the other being attached to the patient. The application is painful and can only be borne for a few seconds. It is claimed to be efficacious for the destruction of warts, nevi, small epitheliomata, sarcomata, lupus, and to abort furuncles and other small areas of beginning suppuration.[1] Riviere,[2] of Paris, probably

[1] Piffard, N. Y. and Phila. Medical Journal, June 16, 1906, p. 1223.
[2] Journal of Advanced Therapeutics, July, 1909, p. 337.

first so employed high frequency currents in the treatment of epitheliomata and superficial tubercular lesions.[1] He employed very short, fat sparks (3 to 5 cm.) from powerful coils. He terms his method "altofrequent cytolysis." The method has been used in inoperable malignant growths of the breast and uterus with asserted success, and its application is advised to the wound when such growths have been removed surgically. He states "that high frequency currents appear to cure small facial epitheliomata and to exercise in certain cases a beneficial influence on the evolution of some malignant tumors."

"They first produce a thermo-electrical-chemical action, the effect of which is to eliminate neoplastic tissues and, if we admit the parasitic theory, to destroy microörganisms and their toxins, and, in the second place, they produce a trophoneurotic curative action, which brings back the vital processes to the normal state."

Fig. 239



The Cannon handle for fulguration. The special object of this handle is to eliminate the disagreeable sparking which occurs when other handles are employed to secure fine, irritating and escharotic sparks, especially when the apparatus is running and the handle not in contact with the patient. This handle short circuits the current until it is in position, and then the depression of the lever breaks the circuit, allowing the sparks to pass to the patient. Good results have been reported from its use for the removal of warts, nevi, callosities, acne indurata, enlarged tonsils, etc. For the treatment of the tonsils, a special curved electrode (*b*) enables one to get a commanding view of the throat, its insulation preventing sparks from touching the patient's teeth.

"It could not be in contemplation to employ the thermo-electrical-chemical action for the elimination of large tumors, for which excision is the elective treatment, but the surgical operation should be followed by the preventive and curative treatment in recurrent cases."

High frequency currents and more especially the monopolar effluve of Oudin's resonator seem to exercise this action by modifying the vitality of the new regions contaminated by the surgeon's knife during the operation, after having drained and disinfected them. This special mode of applying electricity seems at the present time to be one of the therapeutic methods to be tried in cases of inoperable tumor. It must be mentioned, however, that Schulz, of Breslau, has recently

[1] This priority is also claimed by Keating-Hart.

reported thirteen cases so treated without benefit, and that similar lack of success has been the experience of others.[1]

Whether or not this method is superior in such cases to the use of x-rays is a question. It has not been employed much in this country.

Desiccation.—W. L. Clark, of Philadelphia,[2] has recently devised another method, allied in principle to the preceding, which he terms "desiccation." He claims that it is superior to fulguration in that it is less painful and more efficacious. The electrode employed is similar (Fig. 239), but the source of electricity must be a static machine of large output (3 to 6 milliamperes) with a pair of field regulators, devised to give instant and perfect control of the current. Attached to the machine are Leyden jars, the capacity of each being 0.00042 microfarad and a resonator attuned to the capacity. One end of the resonator coil is grounded, and the electrode is attached to the other. The speed is regulated until the machine generates from 1.5 to 3.5 milliamperes, depending upon the effect desired. The sparks cause either blanching of the tissue if dry oı blackening if it is open, and oozing blood followed by a characteristic shell-like appearance, with the formation of a crust or scab. There is more or less inflammatory reaction. As little pain is caused, an anesthetic is usually not required; but if it is, either infiltration with cocaine solution or the inhalation of nitrous oxide may be employed. According to experiments made by B. A. Thomas, it has an antiseptic action also. Good results have been obtained in the treatment of epithelioma, pigmentations, hemorrhoids, ulcerations, tattoo marks, chancroids, warts, moles, and lupus. If the lesion is large, more than one application may be needed.

[1] Progressive Medicine, June, 1911, p. 170.
[2] New York and Philadelphia Medical Journal, June 10, 1911.

CHAPTER XVI

PHORESIS AND OZONE

PHORESIS

This property of the electric current, in addition to the part it plays in its physiological action (pp. 50 and 114), also may be used to introduce drugs into the body through the skin. In using this method, attention must be paid to whether the substance is an anion and diffused from the kathode (anaphoresis), or whether it is a kation and diffused from the anode (cataphoresis). In general, it may be said that bases and metals are electropositive, therefore are repelled from the anode, and are kations, while all acids and substances taking the place of acids are electronegative, and therefore anions. Hence if we wished to introduce the salt of an alkaloid, as hydrochlorate of cocaine, into the skin, it should be placed on the positive pole, the active base going toward the negative while the acid remains at the positive pole (cataphoresis). On the contrary, if we wished to administer a substance that is electronegative, as arsenic in the form of arsenite of potassium, it should be placed on the negative pole, the arsenic as arsenous acid going toward the positive while the potassium will remain at the negative (anaphoresis).

The following table shows the electric relation of the most important substances, and if it is desired to obtain the influence of any one of these, it or one of its chemical combinations should be placed on the same pole, *i. e.*, an electronegative on the negative pole, and *vice versa:*

Electronegative.	Electropositive.
Oxygen.	Hydrogen.
Sulphur.	Silver.
Nitrogen.	Mercury.
Chlorine.	Copper.
Bromine.	Zinc.
Iodine.	Magnesium.
Phosphorus.	Calcium.
Arsenic.	Sodium.
	Potassium.

The introduction of metals has been especially elaborated by Massey (p. 390).

Uses.—Cataphoresis[1] is most generally useful; it is employed with advantage either to produce local anesthesia or to introduce drugs

[1] For full discussion of this subject see the article by Fred. Peterson in International System of Electrotherapeutics, second edition, p. 328.

directly to the diseased part. For the former, watery solutions of either cocaine, aconitine, or chloroform are employed; from the latter, for example, good results have been obtained by introducing the iodides or diluted tincture of iodine by anaphoresis in the treatment of syphilides and affections where painting with tincture of iodine is indicated, and the employment of the salts of lithium or iodine in gouty and rheumatic joints.

A rough method is to saturate the absorbent cotton covering the electrode, which is made the anode or kathode, as the case may be, with either a watery or an alcoholic solution of the drug and placing it over the part desired, while the other electrode is placed at some indifferent point.

Fig. 240

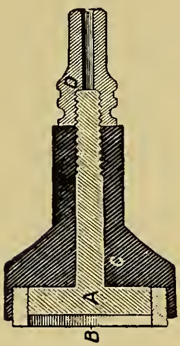


Fig. 241

Peterson's improved cataphoric electrode. *A* is a disk, made of metal, that will not oxidize. The stem which passes through the hard rubber cover *C* is held in place by nut *D*. It also holds the tip for connecting with the battery. *B* is a soft rubber ring, which is held in place by *A*, and at the same time it insulates the skin from *A*, allowing the current to pass from *A* to the skin of the patient through the medicated paper contained in the cavity formed by *A* and *B*.

A constant galvanic current of from five to twenty milliamperes in strength, or from ten to thirty cells, is then passed until the electrode is dry. The current should be both increased and decreased in strength gradually. Owing to the rapid diminution in the density of the current (p. 109) that occurs as soon as the moistened skin beneath the electrode has been passed, drugs cannot be introduced to any great distance within the body, but are soon absorbed by the bloodvessels and lymphatics within the subcutaneous tissues. It is preferable, especially when drugs with pronounced toxic properties are employed, to use a method by which an exact dose can be given. To do this, the electrode devised by Peterson should be used (Figs. 240 and 241). This consists of a flat disk two or three centimeters in diameter, of either platinum, tin, or carbon impregnated with hot paraffin (a nickel-plated surface can be made to answer), which is surrounded at its edge by a soft

rubber rim; this, by its close contact with the skin, prevents loss of the solution by evaporation. Disks of blotting paper are then prepared of a size to fit over the disk and within the rim, an amount of solution containing the dose desired is then dropped upon the paper, which is applied to the part, and the current allowed to flow until it is dry. Peterson has had paper disks prepared impregnated with the proper dose of

FIG. 242

Applicator with straight platinum point.

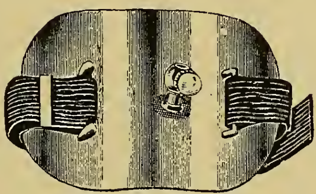
FIG. 243

Curved platinum point.

FIG. 244

Tubular platinum point.

FIG. 245



Wrist electrode for negative pole.

FIG. 246

Double cup electrode.

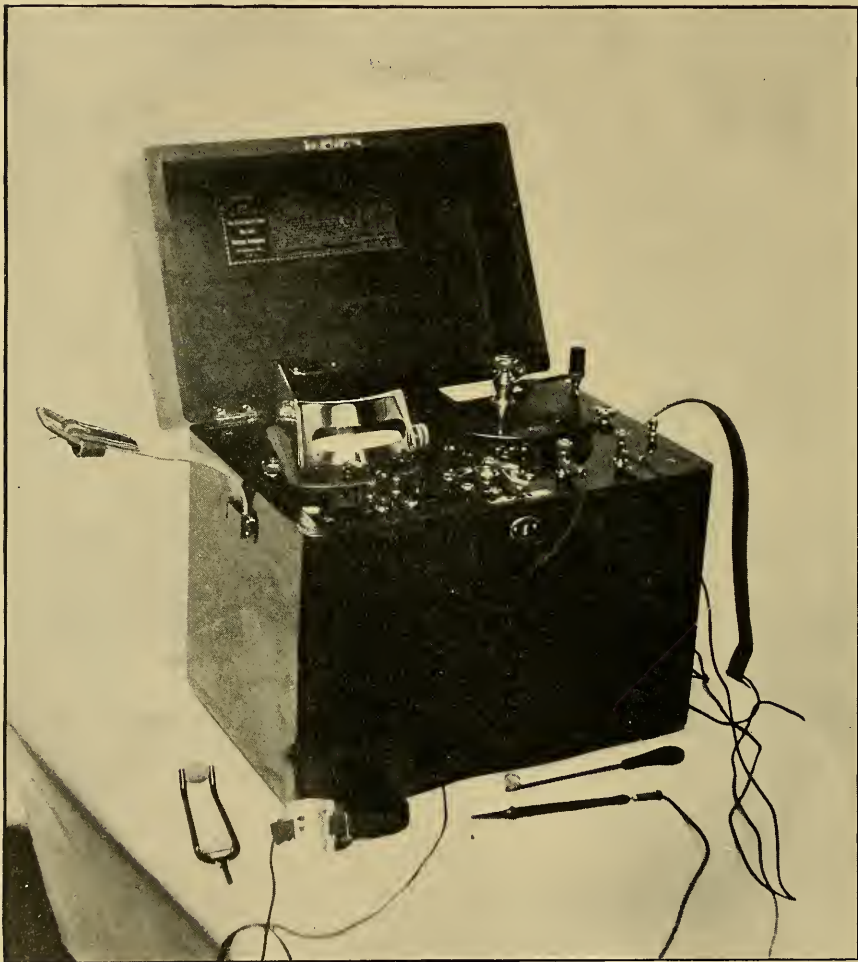
FIG. 247

Single cup electrode.

the drug and allowed to dry, which, when it is desired to use, need only have a few drops of water placed upon them. Morton has employed soluble gelatinous disks in the same way. Peterson's list consists of menthol, 2 grains; helleborine, $\frac{1}{25}$ grain; nitrate of strychnine, $\frac{1}{32}$ grain; iodol, 2 grains; corrosive sublimate, $\frac{1}{8}$ grain; cocaine hydrochlorate, $\frac{2}{5}$

grain; aconitine, $\frac{1}{64}$ grain; potassium iodide, 4 grains; mercury succinimide, $\frac{1}{4}$ grain; lithium chloride, 4 grains. It is well before making the application to remove the oil from the skin by washing with ether. If it is desired to affect large areas, as a joint, a strip of zinc or block tin

Fig. 248

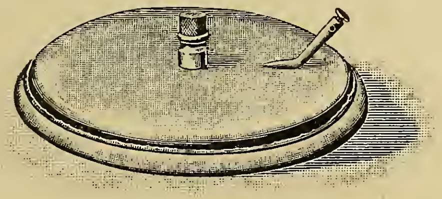


Constant current cataphoric battery.

covered with cloth or absorbent cotton, saturated with the solution, may be bound about the part. If the entire body is to be treated, as in skin eruptions, the electric bath (p. 256) may be utilized, filling the tub with the solution and making it the pole desired.

The *therapeutic indications* are principally the relief of local and superficial pains, as neuralgias, especially if peripheral in origin (p. 178). For this purpose 10 to 20 per cent. solutions of cocaine are preferable,

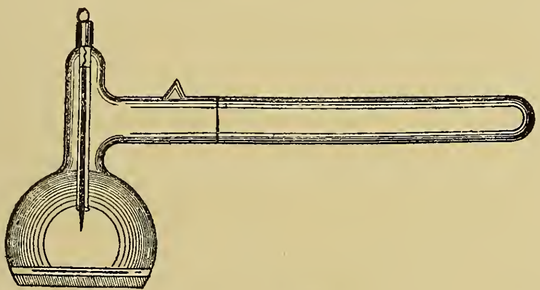
FIG. 249



Cataphoresis electrode.

although aconitine and helleborine can be employed; the production of local cocaine anesthesia for small operations, as small tumors, extraction and filling of teeth, etc. A number of different forms of electrodes

FIG. 250



High frequency cataphoric electrode as designed by Dr. W. J. Morton

have been devised for this latter use (Figs. 242 to 247), also a special form of battery (Fig. 248). Sensitive teeth have been thus rendered insensitive. A 20 per cent. watery solution of cocaine hydrochloride

FIG. 251

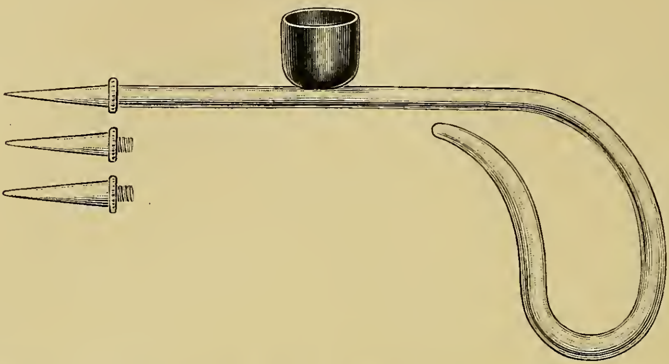
Glass cup static cataphoric electrodes; the sponges are wetted with the desired medication.

is usually employed. If counterirritation as well as anesthesia is desired, a few drops of chloroform can be used.

It may also be used for the relief of local spasm, as blepharospasm, in which either cocaine, helleborine, or atropine may be employed;

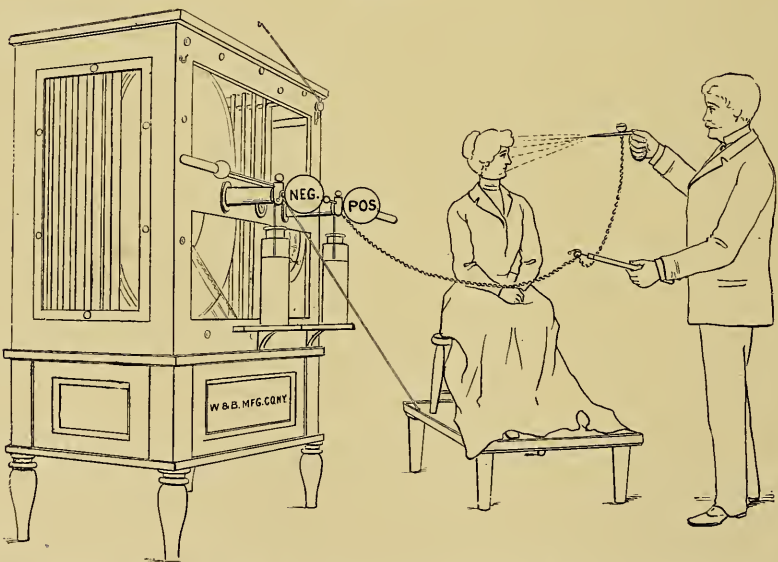
for the topical medication of local lesions, as tumors, rheumatic, gouty, and other swellings, skin diseases, and syphilides, iodine or mercury preparations, or lithium salts being used as indicated. An

Fig. 252



Static cataphoric electrode for the use of heavier oils and medications held in solutions in alcohol, the cup being the receptacle.

Fig. 253



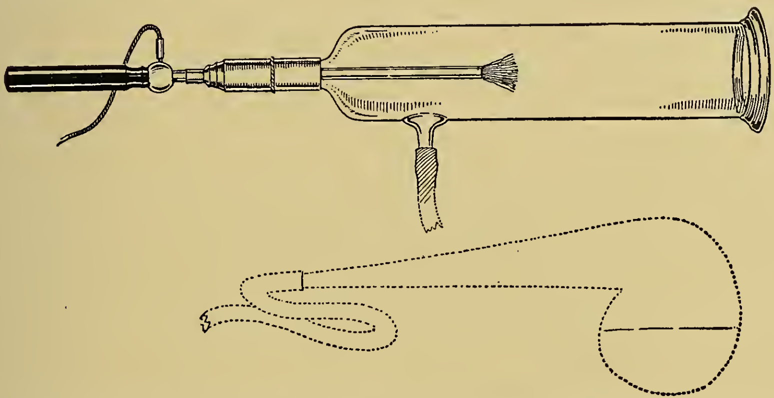
Static cataphoric electrode, showing the connection between patient and operator when treating certain diseases with medication vaporized by the static current.

electric bath (monopolar galvanic, p. 254), containing 4 to 6 grains of bichloride of mercury, is valuable in the treatment of syphilides; of course the water is made the positive pole.

Drugs may be made to penetrate the skin by means of currents of

high frequency. This is probably not a true cataphoric action, but is possibly the result of molecular bombardment or the direct ionization of living tissue. It is necessary that the substance be incorporated in a viscid substance of high electrical resistance. This is painted over the desired area, and is then subjected to a strong effluve for from three to ten minutes. By this means medicaments have been introduced into the lung in tuberculosis. Burch (p. 115) has made a number of experiments and obtained the best results from a mixture of equal parts of oil of turpentine, oil of cinnamon, balsam of Peru, and iodine. This matter is in an experimental stage at this time, and cases have been too few to make any specific claims. Special electrodes have been devised for this purpose (Figs. 249 and 250).

Fig. 254



Static cataphoric electrode. This device is used for applying gaseous substances cataphorically.

Static Cataphoresis.—What has been termed static cataphoresis consists in vaporizing solutions by means of the static current, the electrode being attached to the positive side of the machine. The patient inhales a mixture of ozone (p. 278) and the drug volatilized. Electrodes for the purpose are shown in Figs. 251 and 252. The connections with the machine in Fig. 253. Another form of electrode, by which the drug can be driven against and through the skin, is that devised by Dr. R. V. Wagner shown in Fig. 254.

OZONE

When electric sparks pass through the air, ozone is developed. As ozone in the air in certain quantities is believed to be essential to health, as air rich in ozone is more invigorating than air in which it is deficient, and as it destroys by oxidation (p. 137) certain impurities and germs in the air and elsewhere, endeavors have been made to employ it for

the relief of certain diseases when a powerful oxidizer and tonic is needed.

Fig. 255

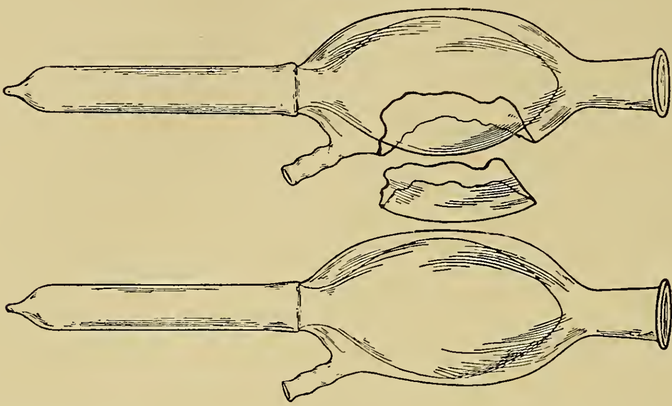
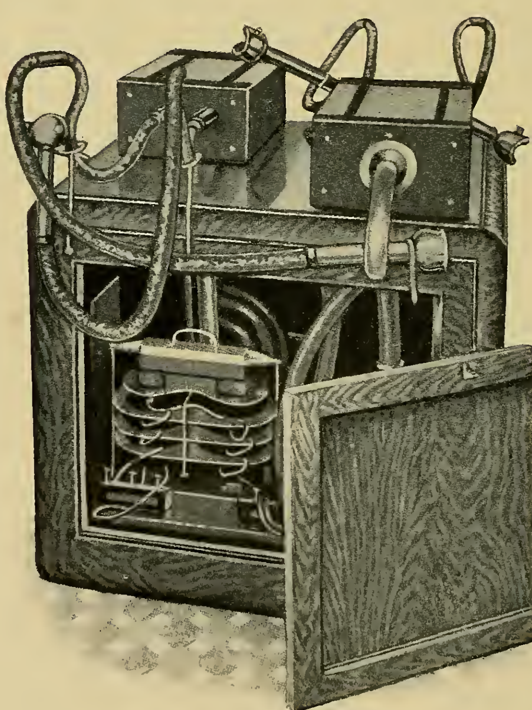


Fig. 256

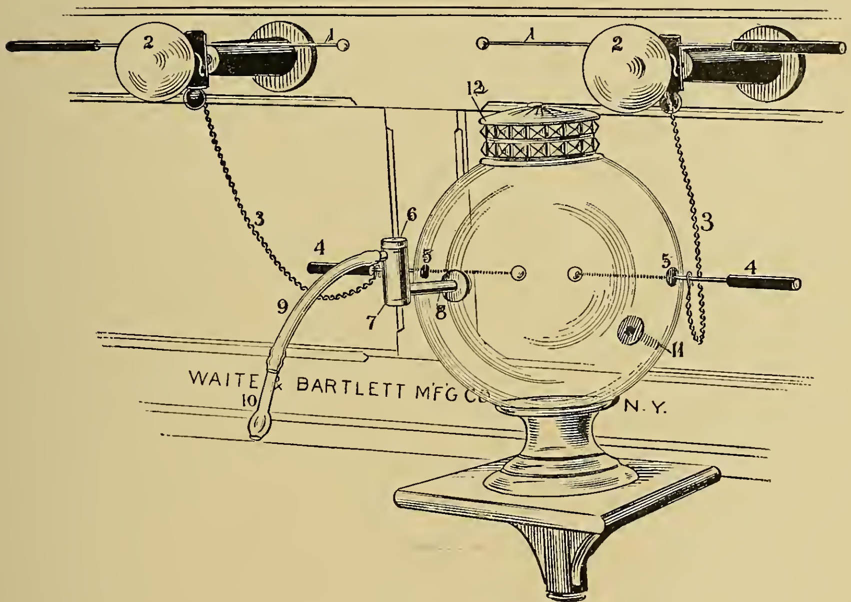


Machine for producing a new oxidizing and antiseptic agent for inhalation purposes.

As the passage of electric sparks through the air is the most convenient method of generating it, they may be used in combination. A

convenient method of giving inhalations of ozone would be to place the patient in a cabinet in which a static machine was in operation, with the discharging rods close enough together for sparks to pass. This method, however, is open to objection, as nitrous products, due to some of the oxygen uniting with the nitrogen to form nitric acid fumes, are formed which are very irritating to the mucous membrane of the respiratory passages. Larat and Gautier (quoted by Turner) found ozone so generated to aggravate the condition of those suffering from phthisis. It must also be remembered that when present in the air in a quantity greater than 0.8 milligram per liter, it may cause death from edema of the lungs. Ozone produced by the effluve (p. 235) of high tension

Fig. 257



Ozone generator for use with static machine.

electricity does not contain much of these poisonous products, and may be used for inhalation by causing the effluve to be given off in the neighborhood of the patient's face. Wagner has devised an arrangement (Fig. 255) by which, in addition to ozone, volatile drugs also may be inhaled. It is termed the "ionizer."

When it does not contain nitric acid fumes it is said to possess valuable therapeutic effects, augmenting the proportion of oxyhemoglobin in the blood, and increasing the number of red blood cells, while the white decrease. It is also said to augment the rapidity of reduction of oxyhemoglobin in the blood. An increase in the frequency of the pulse and rise of arterial pressure may also follow its inhalation. It has also been

asserted that the excretion of urea is increased, the appetite improved and weight gained. Concentrated ozone is bactericidal, but the therapeutic dose is too weak to exert much influence in this direction (p. 137). To obtain pure ozone, various appliances have been devised; one is shown in Fig. 256. It is based on the principle that the less violent the spark the less amount of nitric acid fumes is created, and consists in passing air over electrodes charged with a high potential current, giving off a silent discharge in considerable volume. The electrodes are so arranged as to admit of little or no oxygen passing unconverted, while the nitrogen, which is loosely united with the oxygen, passes through the ozonizer with the least possible change. Volatile oils may be combined with the gas.[1]

A device for use with a static machine is shown in Fig. 257. A high-frequency effluve (p. 235) causes the air of a room to contain more or less ozone, which, if not too great in amount, may prove of benefit, and a certain amount may be absorbed if a vacuum electrode is rubbed over the patient (p. 140). Another form of apparatus, from which it is claimed the patient gets the beneficial effects of a high frequency current, ozone, light, and heat, has been devised by Curtis.[2]

From its asserted physiological action, ozone should be of service in anemia, chronic nephritis, tuberculosis, neurasthenia, and gout.

[1] Journal of Advanced Therapeutics, August, 1904, p. 512 et seq.
[2] New York Medical Journal, January 18, 1902, and February 1, 1902.

CHAPTER XVII

ELECTRIC LIGHT, MOTORS, AND MAGNETISM

THE ELECTRIC LIGHT

Both the local and general effects of light and heat are now much employed in therapeutics. The use of these agents is known as *phototherapy*. Electricity affords both a convenient and constant mode of obtaining them. As is well known, by means of a prism sunlight can be decomposed into a number of different colors, termed the solar spectrum. These colors are produced by waves of the ether of different lengths and rapidity, ranging from red, the slowest and longest, to violet, the shortest and most rapid. In between these limits are orange, yellow, green, blue, and indigo. In addition, however, are other rays, which cannot be perceived by the eye, and hence are not perceived as color. These consist of the infrared, the wave length of which is longer than that of red, and the ultraviolet, whose wave length is less than that of violet. The former, together with the red and orange, are heat rays; the latter have chemical properties, and are known as the *actinic rays*. These higher frequencies (actinic rays) are manifested by their effects on living tissues (*vide* Physiology) and their power of causing fluorescence in certain substances. Thus, if a ray of sunlight be passed through a prism so as to be drawn out into the spectrum, and let the spectrum so formed fall on a piece of paper painted with a solution of sulphate of quinine, the spectrum will be seen to be extended beyond the violet end, the invisible rays being made visible by this substance. Platinocyanide of barium and willemite are frequently used to demonstrate their presence; the former gives a clear, nearly white fluorescence, the latter a greenish. Owing to the fact that certain rays of the spectrum may be absorbed by certain substances, and that others will only let certain rays pass through them, we are enabled to utilize, if desired, the effects of some to the exclusion of others. Thus, actinic rays will not pass through glass, especially red glass, but will through quartz, through which light rays do not pass.

PHYSIOLOGY

Light and heat undoubtedly considerably influence metabolism, as they quicken the functional activities of the cells by stimulating them, promote elimination through the sweat glands, and as they produce

more or less hyperemia, an increased influx of blood to the part is induced, thereby favoring nutrition, absorption, elimination, and phagocytosis. By stimulating the peripheral nerve endings, a reflex stimulation of activity in remote organs is also caused. Too prolonged exposure produces a feeling of exhaustion similar to that experienced by those exposed for a long time to a hot sun (p. 283). The actinic rays are irritating and destructive, causing hyperemia, vesication, and pigmentation of the skin long exposed to them; they also increase oxidation, and have considerable destructive action upon certain forms of germ life.

Red light has been asserted to have a good effect upon certain forms of inflammation and infections (p. 293).

Blue light is asserted by many to have anesthetic and soothing properties.

METHODS OF APPLICATION AND THERAPEUTICS

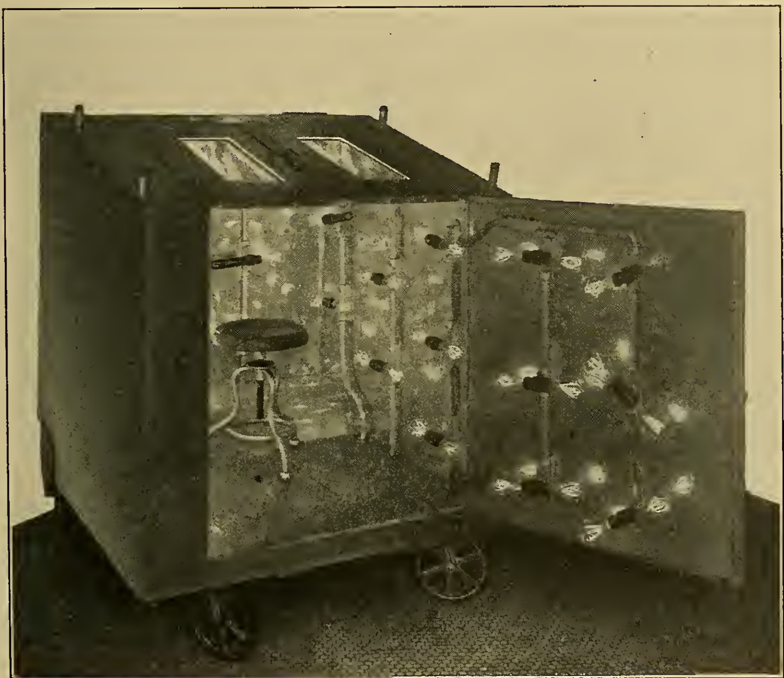
The sources of radiant energy used in therapeutics are both natural and artificial. The former consist of sunlight, radium, and other radioactive bodies; the latter, which alone concern us here, are the incandescent, electric arc, and mercury vapor lamps, the Crookes tube, and electric spark. These artificial sources do not all produce light possessing the same qualities, from some it being poor in the higher frequency or ultraviolet rays, while from others it is particularly rich in these. It may be put down as a general rule that all treatments, whether general or local, should at first be of brief duration and gradually increased if no unpleasant effects are caused; fifteen to twenty minutes may be put down as a maximum. Static or high frequency electricity or vibratory massage may be used afterward when indicated. All clothing over the part being treated should be removed.

Incandescent Light.—For most purposes the incandescent light is most convenient. It contains a large percentage of heat rays and is poor in actinic rays. As these do not pass through ordinary glass, such as are present are absorbed by the glass of the bulb and hence do not reach the patient. Light from this source may be used for general and local effects. For the former, what are known as *incandescent light* baths are employed. Kellogg,[1] who was one of the first to employ this method, uses two forms of cabinet. One consists of a compartment about eight feet high, upon the inside of which are placed from fifty to sixty incandescent lamps. The spaces between the rows of lamps are filled with either glass or metal mirrors to increase the action of the lights by reflection (Fig. 258). The cabinet is so arranged that either the entire body of the patient sitting upright can be exposed to the light, or the head may be excluded, as in the ordinary vapor bath. The other

[1] Hydrotherapeutics, p. 707.

form of cabinet is of such a shape that the patient can be recumbent and the lights, from sixty to ninety, are upon three sides (Fig. 259). The patient lies upon a couch provided with rollers, which can be pushed entirely within the cabinet or only so far as to expose such portions of the body as is desired to be exposed to the light. Crothers,[1] as an eliminant after alcoholic debauches, uses a room five feet square and six feet high, lined with tinned plate and containing one hundred sixteen-candle power incandescent lights. From this he claims most excellent results. For more local action, arrangements such

Fig. 258



Electric light bath cabinet. (Jefferson Hospital, Philadelphia.)

as are shown in Figs. 260 and 261 may be utilized. The patient should remain not over fifteen minutes in the bath, or less if copious sweating is caused, and it should be followed by either a cool douche or sponge. While taking the treatment the head should be kept cool by means of a towel rung out in cold water. Such a bath too long continued causes difficulty in breathing, palpitation of the heart, and nervousness. Its indications are those in which elimination and increased action of the skin are wished for, and where it is desired to cause the absorption

[1] Philadelphia Medical Journal, December 28, 1901, p. 1131.

of exudates, viz., rheumatic and gouty conditions, myalgias, nephritis, alcoholism, inflammatory bone diseases, exudates in the pleural and peritoneal cavities, diabetes, and obesity. *Raynaud's disease* and Thrombo-angiitis obliterans[1] have been benefited by the incandescent light, a strength of from 500 to 600 candle-power being used. From its power of increasing the flow of blood to parts to which the light is directed, and hence increasing phagycytosis, it may be used in infec-

Fig. 259

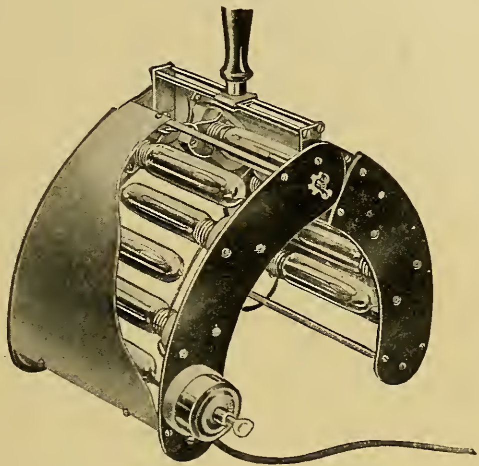
Horizontal electric light bath. (Kellogg.)

tious processes. The hyperemia produced makes the use of light (especially arc light, from its resemblance to sunlight) indicated in alopecia and psoriasis. The smaller lamps (Fig. 262), for local use, may be employed with advantage. The form shown in Fig. 263 is also convenient. Glass screens of blue, orange, or red can be adjusted

[1] Buerger, American Journal of Medical Sciences, October, 1908, p. 567.

over the point of these lamps and the therapeutic effect of these colors obtained (pp. 291 and 293).

Fig. 260



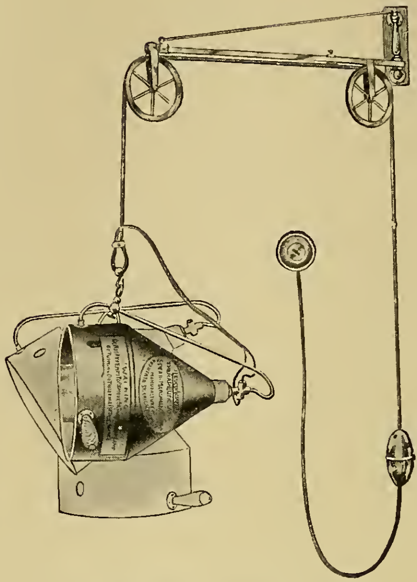
Edho radiant light and heat bath, skeleton view.

Fig. 261

Edho radiant light and heat bath, showing method of treating rheumatic shoulder. Clothing may be removed if desired.

Small lamps may also be employed for general treatments in neurasthenia and kindred disorders, the applications being first made to the spine, then to the front of the body, then to the spine. For marked

Fig. 262



The leukodescent therapeutic lamp.

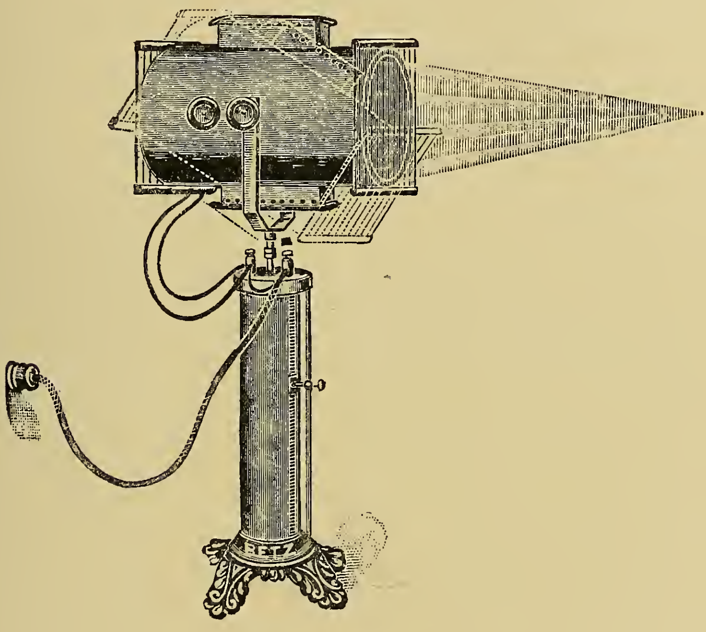
Fig. 263

McIntosh style "B" therapeutic lamp, 50 candle-power.

sedation, blue light may be applied to the head (p. 292). The Nernst lamp, which differs from the ordinary incandescent lamp in that the filament is not enclosed in a vacuum but is exposed to the air, is said to give a light of great actinic power, but of less heat than the ordinary style of lamp.

Arc Light.—The arc light may be employed to meet similar indications as the incandescent light, but is not so convenient, especially for use in cabinets, as the actinic rays, in which the light so generated is rich, cause pigmentation and possibly vesication of the skin, irritating vapors, consisting of nitrous acid and ozone, are given off, hot particles

Fig. 264



Actinolite.

fly off from the carbon electrodes, and much more current is required to give the same results than is necessary for the incandescent lamp. If it is used in a cabinet, the head of the patient should always be outside, otherwise the vapors above mentioned may cause disagreeable, possibly serious, results. This form of light is usually employed in local infectious processes where the germicidal effects of the ultraviolet rays are desired. A convenient form of lamp is that made by Betz. It is constructed on the principle of the marine search-light, and includes red screens for cutting out the ultraviolet rays and blue screens for cutting out the heat rays if desired (Fig. 264). The effects of this light upon local conditions was first brought to general attention by Finsen.

Treatment of Lupus Vulgaris and Other Skin Diseases.—The remarkable results obtained by him and since by others in the treatment of *lupus vulgaris* are well known. Thus, in his latest book, Finsen gives the following statistics: Of 804 cases treated at the Finsen institute during a period of seven years, 412 were cured, of which number, 124 showed no recurrence in from two to six years, and of which 288 had been free from recurrence for a period of less than two years, 192 were nearly cured, and 117 remained under treatment. The results being favorable in 94 per cent. and unfavorable in 6 per cent.[1]

FIG. 265

Arc lamp (compressor held to focus rays).

Favorable results have also been obtained in *lupus* erythematosus, acne, acne rosacea, alopecia areata, epithelioma, relief of pain and hemorrhage in uterine cancer, tuberculosis cutis, ichthyosis, vitiligo, and nevus. In the treatment of nevus the best plan is to destroy the largest vessels by electrolysis (p. 369), and immediately follow this with the ultraviolet light, keeping up all compression possible upon the dehematized areas (Allen). Benefit has also been reported in eczema, chronic ulcerations, actinomycosis (late stage), adenoma sebaceum, acne pustulata, sycosis, and psoriasis. For more extended information the reader is referred to modern works on dermatology.

Technique.—All detachable crusts, scales, ointments, etc., should be removed with ether and green soap. The neighboring skin can be

[1] Die Bekämpfung des Lupus Vulgaris, Jena, 1903.

protected by applying a square piece of adhesive plaster with a round opening over the area to be treated, or tinfoil or red silk can be used. For the deeper tissues to be influenced, the part should be dehematized by compression, as ultraviolet rays will not penetrate tissues in which blood is circulating (Fig. 265).[1] The exposures should be from a few minutes to an hour, according to the effect produced, and usually every other day. The inflammatory zone may be either dressed with unguentum rosæ or other measures suitable for an irritated skin employed. A simpler form of lamp for similar purposes is also made. For the treatment of affections where the light does not have to be so concentrated as when treating lupus it answers every purpose. By the use of a similar appliance, Freudenthal[2] claims excellent results in the treatment of tuberculosis of the larynx. *X*-rays are also employed in some instances more conveniently and efficiently in the treatment of the various skin affections for which light is recommended (Section VII).

Fig. 266

Spark-gap lamp for ultraviolet rays.

The electric spark either from a static machine or Rhumkorf coil may be used to generate ultraviolet rays. In such lamps the electrodes are usually of iron, and have a condensing lens of quartz (Fig. 266). Another form is the so-called "mercury vapor lamp" (Fig. 267), based on the principle of the fluorescence excited in mercuric vapor by the passage of an electric current through it. In the Cooper-Hewitt light this is the 110 volt direct. It consists of a vacuum tube one inch in diameter and two to four feet long, containing a quantity of metallic mercury. The current is transmitted through the vapor and makes a light rich in violet rays but poor in ultraviolet and free from red.

In general it may be stated that all lamps, whatever the source of light, should contain a system of reflecting mirrors, screens for separating heat from the actinic rays, and *vice versa*, a mechanical means for accurately adjusting the beam of light, and, if the actinic rays are to be

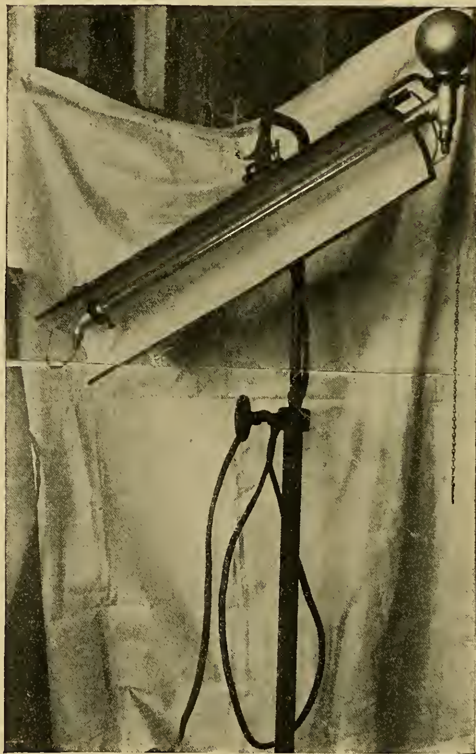
[1] In localities that cannot be dehematized by compression, Piffard (Medical Record, March 7, 1903) has shown that the introduction of adrenalin chloride by cataphoresis will have the desired effect.

[2] New York Medical Journal, July 12, 1902, p. 51.

employed, a compressor of quartz (these rays will not pass through glass). When the arc lamp is being employed it may be necessary to keep it cool by means of water (Fig. 268). A description of the Finsen lamp (Fig. 269) is here given.

It consists of a 60 to 80 ampere lamp of about 35,000 candle power, with an upper positive and lower negative carbon. When the current is turned on, a crater-like excavation is formed in the upper carbon, from which the rays are directed downward and outward, striking

Fig. 267



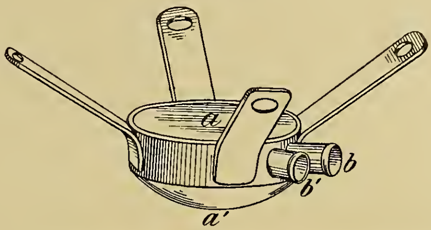
Mercury vapor lamp. (Tousey.)

the upper lens in the copper tubes. The rays are rendered parallel, so that they pass to the farther extremity of the tubes, where a concentrating lens converges them upon the area to be treated. A coil carries distilled water, which circulates in metallic sheaths about the lenses at the tube's extremity. Another cooler carrying distilled water may be combined with the compressor.

Iron electrodes give off a light richer in actinic rays than do those made of carbon.

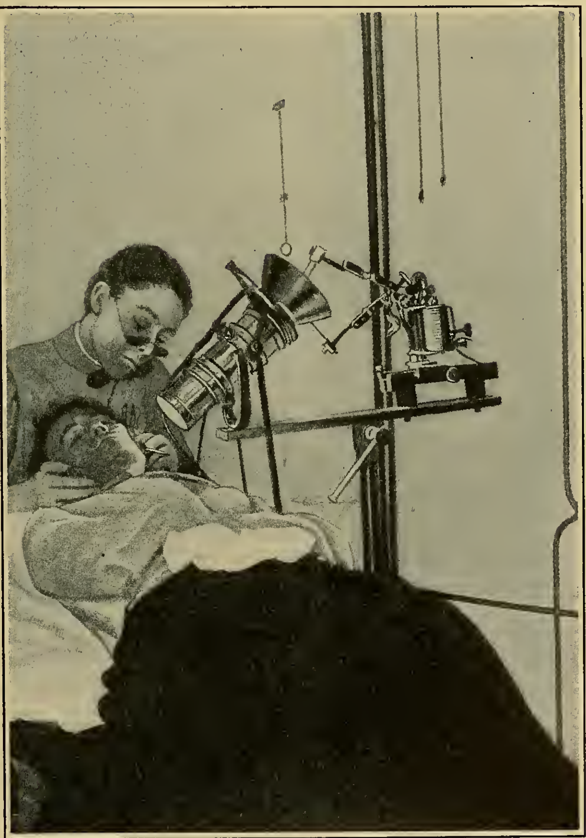
Blue Light.—Blue light has been claimed to have a marked general sedative and local anesthetic influence. Tracy[1] states that he has per-

FIG. 268



a, rock-crystal lens. The projections *b* and *b′* are for attaching water-cooling tube and outflow.

FIG. 269

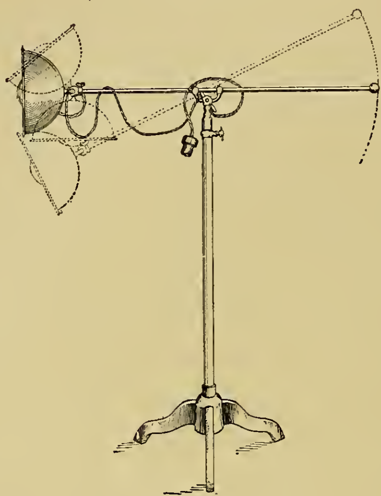


Finsen-Reyn lamp in operation. (Allen.)

[1] Boston Medical and Surgical Journal, November 6, 1902.

formed minor operations without pain after its application. Neuralgia and neuritic pains have also been so treated, and it is claimed that electric baths, the glass bulbs being made of blue glass, have quieted general nervousness and produced sleep in cases of neurasthenia, insomnia, etc.[1] Ordinary incandescent lamps with bulbs of blue glass or the Minin lamp (Fig. 270) may be used. Finsen has claimed that by the use of light from which the actinic rays have been excluded a beneficial influence may be exerted upon the course of variola and measles.

Fig. 270



Minin's lamp. (Allen.)

To carry the treatment out properly, the patient must be in a room into which no light can enter excepting through red glass (as a photographic dark room). All light necessary in the room should be supplied by a candle. In the hands of Schamberg and Fox this method was of no use, but it was not carried out as strictly as recommended by Finsen. Allen[2] states that the use of eye-glasses of red glass prevents seasickness.

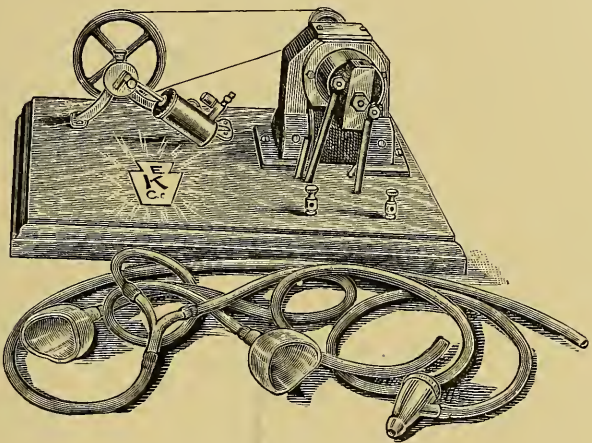
MOTORS, VIBRATORS, CAUTERIES

The electric motor, such as shown in Fig. 44, is employed for many purposes, notably in running the static machine, engines for dental work, and to open bony cavities, as the skull (p. 350). For such purposes the speed is regulated by a controller (Fig. 45). They are used also as motive power for centrifugators in the examination of

[1] Journal of Advanced Therapeutics, June, 1908, p. 308.
[2] Radiotherapy, Phototherapy, etc., p. 452.

urine, etc. Small motors are convenient to run instruments employed to massage the ear-drum and eye (Fig. 271) (p. 353). It has also made possible the development of vibration or vibratory massage, a most useful form of treatment in motor paralysis due to various causes, constipation, local inflammations, headaches, especially when due to rheumatism or gout (indurative headache), muscular rheumatism, etc. There are many varieties of appliance for this purpose. A type is shown in Fig. 272. Various forms of applicators are also made. By its use the circulation is stimulated locally, the bloodvessels dilated, the absorption of exudates increased, secretions excited, and local analgesic effects produced.

Fig. 271



Eye and ear masseur.

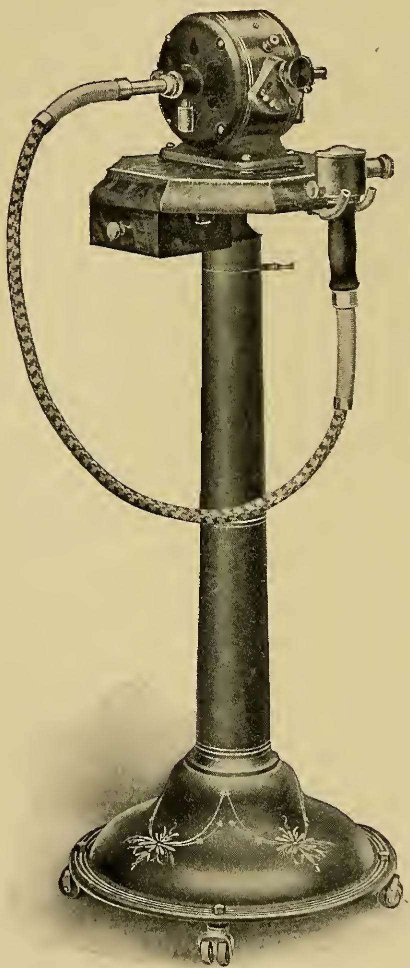
The *electrocautery* (p. 48) is used to control hemorrhage, to destroy cancer, especially of the uterus, and small growths, and to stimulate ulcers. The technique of its application will be found in the chapters upon diseases of the throat, nose, eye, diseases of women, and skin. Downes[1] has employed it to control hemorrhage in abdominal operations, principally hysterectomies and panhysterectomies. The instrument is termed the electrothermic angeiotribe. The method has been endorsed by other surgeons, Hirst[2] strongly recommending it in hysterectomy for cancer in preference to the ligature. A full account of the technique, indications, and description of the instruments will be found in the articles by Downes (*loc. cit.*) and Bovée.[3]

[1] Journal of the American Medical Association, 1901, xxxvii, 419 et seq.
[2] Diseases of Women. p. 62.
[3] Journal of the American Medical Association, May 5, 1906, p. 903.

MAGNETISM

At this time there is no evidence that exposure to the magnetic force produces any physiological effect upon the human organism. Peterson and Kennelly experimented in Edison's laboratory with exceedingly powerful magnets. As a result of these they concluded "that the human

Fig. 272



Vibrator.

organism is in no wise appreciably affected by the most powerful magnets known to modern science; that neither direct nor reversed magnetism exerts any perceptible influence upon the iron contained in

the blood, upon the circulation, upon ciliary or protoplasmic movements, upon sensory or motor nerves, or upon the brain."[1]

The application of magnets to areas of hysterical sensory paralysis has been attended with good results, but in these cases the cure is due to suggestion and not to any virtue in the magnet itself. The observations made above apply to the use of permanent magnets. Another form of magnetotherapy lately introduced is the so-called permeating electricity method of E. K. Mueller. In this the patient is exposed to an undulating magnetic field produced as follows: The apparatus consists of a wire spiral of about 200 windings, which is traversed by a current of high intensity, *i. e.*, 20 to 60 amperes, but of low tension and frequency. This produces a magnetic field of low frequency, but high intensity, the lines of force of which penetrate the patient's body. The magnet consists of a core composed of layers of a paramagnetic material as soft iron or nickel which contains a central space for a system of cold water circulation. The core is surrounded by the coil mentioned above, which is also provided with a cooling arrangement. The coil is supplied with either a continuous or alternating current, which is varied periodically in its intensity; the direction is immaterial. This undulating current will always produce alternating currents in the windings of the coil by self-induction, and these in turn will produce an undulatory magnetic field. Rodari[2] gives the following indications for its employment: Neuralgias, occupation neuroses, diffuse headaches, muscular rheumatism, subacute articular rheumatism, acute gout, irritative forms of neurasthenia with insomnia, tabetic pains, angina pectoris, and hyperesthesia of the gastro-intestinal tract.

It is said to increase the oxyhemoglobin of the blood and exert a sedative influence on the vasomotor system. T. Cohn[3] says that further investigation is necessary to substantiate these claims.

[1] Transactions of the American Electrotherapeutic Association, 1892.
[2] Berliner klinische Wochenschrift, 1901, Nos. 23 and 24.
[3] Electrotherapeutics, p. 261.

SECTION VI

SPECIAL ELECTROTHERAPEUTICS

By this we mean the preferable forms of current and the means of applying the same in the different diseased conditions in which electricity is indicated. Diseases in which the therapeutic influence respectively of x-rays, electric light baths, and ozone is indicated are mentioned in the chapters devoted to these agencies. Sections II and IV should be carefully read in connection with the foregoing.

CHAPTER XVIII

DISEASES OF THE NERVOUS SYSTEM

ORGANIC DISEASES

Diseases of the Brain.—Electricity in the form of the galvanic current has been recommended by some in the treatment of the various general and focal diseases of the brain. It is exceedingly doubtful if it has any influence for good, and in some cases may do harm. As stated on page 129, the brain itself receives very little if any of the current.

If used, it may be employed as follows: Two large electrodes are placed, one on the forehead, the other at the nape of the neck. The current (galvanic) is then gradually increased from zero to a strength of about 5 milliamperes. This is allowed to pass from two to five minutes, and then is gradually decreased to zero. To produce cerebral anemia it is advised to place the anode on the forehead, the kathode being at the nape of the neck. If the production of hyperemia is desired, this position of the poles is reversed. Subaural galvanization (p. 226) may also be employed.

A much surer and safer method for the production of *cerebral anemia* is the application of either the dry faradic brush (p. 223), high frequency effluve (p. 235), or static sparks (p. 227) to the extremities.

While the diseased part itself cannot be benefited by the current, the consequences produced by it often can. This is best seen in the paralysis, either motor or sensory (usually hemiplegic), contractures, and vasomotor disturbances which result from either *cerebral hemorrhage, thrombosis,* or *embolism.* The *motor* paralysis is best treated by stimulating the muscles with the faradic current; this should not be begun until all symptoms of acute disturbance, *i. e.*, headache, fever, stupor, etc., have disappeared, which is usually in about two or three weeks. The applications should be made about three times weekly (p. 206). Much may be done with electricity to prevent the occurrence of contractures in these cases. As these are due to the overaction of one group of muscles overpowering their antagonists, the treatment should be directed to strengthening the weaker or antagonistic muscles. In hemiplegia these are usually the extensors in the arm and the quadriceps femoris and muscles supplied by the external popliteal nerve in the leg, and these are the only muscles which should be stimulated by the current. If *contractures* already exist, the relaxed antagonistic muscles should be stimulated by the faradic current, while stabile anodal applications are made to those which are contractured. Faradism also benefits the vasomotor symptoms (cyanosis, numbness, etc.), but these are best treated by the employment of static sparks. *Anesthesia,* if it exists, may be treated with the dry faradic brush.

The various forms of cerebral spastic paralysis of childhood may also be sometimes benefited by these procedures.

Diseases of the Spinal Cord.—The remarks made above concerning the probable futility of electricity affecting favorably organic lesions themselves of the brain apply likewise to the spinal cord (p. 129). While the current, especially the galvanic, has been claimed to affect favorably *myelitis* and *sclerosis,* it seems doubtful if it really does so, and the beneficial results of its use in these conditions are limited to the amelioration of the symptoms—*i. e.*, paralysis and pain—produced by them. If, however, it is desired to employ the galvanic current for its direct action upon the diseased part, large, well-moistened electrodes should be placed over the cord so as to include the probable seat of the disease and strong currents, without interruption, used. As derivatives, when the cord is believed to be congested, either the rapidly interrupted faradic current or static sparks to the legs may be employed. Snow recommends for this purpose the application of the *wave current* over the muscles of the back. He says: "A sixteen-plate Holtz machine in any case, and one having but eight revolving plates in most cases, will produce a degree of vibration and tissue contraction which will penetrate the muscular structures and most dense fibers of the human frame with sufficient energy to favorably affect a congestive process in the recesses of the spinal cord as no other known means in the hands of the profession today."

Other forms of high tension current may also be employed, the current being directed to the back and extremities by means of the glass

vacuum electrode (pp. 235 and 248); otherwise electricity should never be employed in acute conditions.

Chronic Spinal Meningitis.—Electricity may be applied to the paralyzed muscles by the methods detailed on pages 222 and 224. As in this disease the anterior nerve roots in the affected area are compressed by exudation, the muscles supplied by these roots will be atrophied and may show various degrees of DeR, in which event it will be necessary to employ the galvanic current. Of course, not much benefit can be expected until the exudation and consequent compression is relieved by other means. As a derivative, the methods advised in myelitis may be employed.

Chronic Myelitis.—The same rules as regard the paralyzed muscles apply here as in chronic meningitis. In addition, the paralyses of the sphincters of the bladder and rectum, with the consequent incontinence of urine and feces, may be helped by the use of electricity. If the lesion is believed to be in the lower sacral segments, affecting directly the centres which control these muscles, galvanism, the current being interrupted several times, should be employed. If the lesion is situated higher up, the centres not being directly affected, faradism, preferably the slowly

Fig. 273

Urethral electrode, with platinum tip.

interrupted current, will answer the purpose. One of two methods may be employed: One pole (if galvanism is being used, the anode) is placed either over the lumbar region or on the perineum, while the other is placed above the symphysis pubis, or, instead of placing one pole over the bladder, we may introduce it in the shape of a urethral electrode (Fig. 273) as far as the neck of the bladder, or even into it. When the latter method is used the bladder should be full, either of urine or salt solution, and the electrode carefully sterilized. The applications should be made about three times weekly and not too long continued. In the case of the anal sphincter, one electrode, as in the case of the bladder, is placed over the lumbar region, and the other (Fig. 278) is introduced just within the anus. For the treatment of bed sores, see page 371.

Acute Anterior Poliomyelitis.—Much can be done in this disease by properly used electricity to restore the degenerated muscles. Its use should be persisted in for a long time. Improvement in muscles that will at first give no response to the current may occur after months of treatment. When the muscles will respond to it, the faradic current (p. 222) may be employed. In the case of muscles which will not respond to faradism, either the galvanic, galvanofaradic, or sinusoidal

currents should be used (pp. 222 to 227). When they either will respond only to a very strong galvanic current or will not respond at all, the proper plan is to use the kathode labile over those affected for from five to ten minutes; for it must be borne in mind that the use of very strong interrupted currents in a muscle much degenerated may destroy the little vitality that it possesses. When they are used without sudden interruption, as above advised, currents as strong as can be borne may be used. The applications should be made at least every other day, and for a while may be made daily. It is well after several months of treatment to desist for a week or two and then resume as before. Hope of benefit should not be lost until electrical treatment, together with the other measures that are proper, have been persisted in for at least a year. It is usually recommended that electric treatment be not begun until acute symptoms have subsided. Williams,[1] however, recommends that it be begun during the first week of the disease. He says that the use of the galvanic current at this time prevents atrophy of the spinal cells, as the muscle contractions react upon the cells, and improves their nutrition, and relieves the pains and aches caused by the sagging of relaxed joints.

Progressive Spinal Muscular Atrophy.—The same rules apply here as in acute poliomyelitis, but the hope of obtaining benefit is not so good. Care must be taken not to exhaust the muscles by overtreating them.

Tabes Dorsalis (*Locomotor Ataxia*).—Some observers claim excellent results in this disease by the application of the galvanic current to the cord, as described on page 298. If used it should be applied every other day for ten minutes for a period of six weeks, being followed by the application of the dry brush to the extremities Its use should then be stopped for six weeks, after which the treatment is continued for another six weeks. This routine may be continued for several months, when, if no improvement ensues, it should be stopped.

The powerful application of the static wave current and long percussion sparks (pp. 227 and 259) over the cord and friction sparks (p. 230) to the legs has been highly recommended by some electrotherapeutists (Snow and others). Snow says that by these means there are very few cases of tabes that cannot be greatly benefited, and in the incipient stages cured. There can be no doubt of the value of these procedures, but they should not be used to the exclusion of other measures, viz., rest, massage, forced feeding, etc. It is claimed that either sparks, spray, or the brush discharge locally applied will greatly relieve tabetic pains. The application of friction sparks as strong as can be borne, applied to anesthetic areas, may improve sensation.

Numbness and other varieties of paresthesia and the pains may also be much relieved by either the use of the dry faradic brush (p. 223) or friction sparks (p. 230).

It is claimed that gastric crises may be helped by the sinusoidal

[1] Journal of the American Medical Association, January 21, 1911, p. 192.

current, one electrode being placed over the stomach, the other over the back. Weakness of the bladder may be treated as described under chronic myelitis (p. 298). It is possible in some cases that optic atrophy may be arrested by the use of galvanism employed as described on page 327.

Diseases of the Peripheral Nerves.—It is in diseases of the peripheral nerves that electricity is most frequently used, and it is in these that the best results are obtained. Affections of both motor and sensory nerves are amenable to its use.

Motor Nerves.—These may suffer from either destructive or irritative lesions; in the former the resulting symptoms are more or less paralysis and atrophy of the muscles supplied by the affected nerves, while in the latter spasm, either tonic or clonic, is the resultant symptom.

In treating destructive lesions of nerves we may use electricity, both to influence the lesion itself, and, what is more important, to improve the nutrition and consequently regenerate the muscles affected by this lesion. When the condition is very acute, as an acute neuritis, the only electrical treatment permissible is the passage of a galvanic current, without interruption, down the course of the nerve. Thus, if it is the brachial plexus which is involved, the anode may be placed either just above or below the clavicle and the kathode held in the hand; if the sciatic nerve, the anode should be placed over the sacrum and the kathode either in the popliteal space or on the sole of the foot, according to the location of the lesion. This should be done daily for from ten to fifteen minutes, the current being both increased and decreased gradually, and if there is any increase in pain caused it should at once be abandoned.[1] In the case of nerves which have been divided and recently sutured, or when the seat of the lesion can be located, a similar plan of treatment to that just described should be carried out, excepting that the kathode can be placed over the injured or diseased part and the anode at the distal extremity of the nerve. After the acute symptoms have subsided measures to improve the condition of the muscles are in order. When they are much degenerated and very strong currents are required to produce contractions, it is well, instead of attempting to do so, to place the anode over the nerve and apply the kathode labile to the affected muscles, as has been recommended in the treatment of acute poliomyelitis (p. 300). The faradic current is usually employed if the muscles will respond to it, using one of the methods described on page 222. If they will not, we can use either the galvanofaradic, sinusoidal, or galvanic current, according to the methods described on pages 222 to 227. In chronic neuritis excellent results may be obtained from the use of either the static wave current (p. 259), static sparks (p. 227), or the high frequency current applied by means of the effluve (p. 235) or vacuum electrode (p. 238).

[1] As the spinal nerves are mixed nerves and hence contain sensory fibers. Most inflammatory affections of these nerves are attended by more or less pain.

Localized spasms, while usually functional in their nature, may for convenience be here discussed. The best electrical method of treating these is to use the galvanic current, placing the kathode at an indifferent and remote point and placing the anode over the supplying nerve and affected muscles in turn (see Electrotonus). The seance should last from ten to fifteen minutes, be repeated at least once daily, oftener if possible, and the current strength should be about five milliamperes; it should be increased to this strength gradually and decreased gradually when it is desired to cease the application. The rapidly interrupted faradic current applied to the muscles has also been used for this purpose, and Rockwell has recommended the combined galvano-faradic current (p. 221).

Sensory Nerves.—As in the case of the motor nerves, sensory nerves also suffer from either destructive or irritative lesions. The result of the former is a greater or less degree of sensory paralysis. When the lesion is acute, the only electrical treatment permissible is that described for acute lesions of motor nerves; if it is either chronic or the acute symptoms have subsided, we may daily treat the resulting anesthesia by employing either the dry faradic brush (p. 223), static or friction sparks, or the high frequency effluve or vacuum electrode.

The predominant symptom of an *irritative lesion of a sensory nerve* is pain. The treatment of this will differ according as it is felt in a considerable area, as in neuritis, or is apparently more localized, as in many of the neuralgias. In the former case the treatment, by allowing a continuous galvanic current to flow either down or up (or both alternately) the course of the nerve for from five to ten minutes, is often efficacious, and is alone to be used in acute conditions. In chronic cases, the static breeze may be employed, or even static sparks can be applied along the course of the nerve; this may increase the pain at first, but if it is to be of any benefit should soon be followed by improvement. The high frequency current applied either as the effluve or with a vacuum electrode over the course of the affected nerve is often of great service (p. 249). In the treatment of *neuralgias*, many of which are of functional origin, but may be conveniently treated of here, as the treatment in either case is the same, the galvanic current is usually the most efficacious. The kathode should be placed at an indifferent point, and the anode (a small electrode) over the painful points in turn for five minutes each. The strength of current, excepting about the face, when it must be weaker, should be from five to ten milliamperes and is to be increased to and decreased from the maximum strength gradually, the seances should be at least daily and oftener if possible. *Hyperesthesia* of the skin may also be treated by this method with advantage, the anode being placed over the nerve trunk or trunks which supply the affected area (see Electrotonus). The static breeze and sinusoidal current may also be employed for this purpose.

In the case of mixed nerves with consequent motor and sensory symptoms these methods of treatment may frequently have to be combined.

Diseases of Special Nerves.—Certain nerves and some diseases of nerves may require either modifications of or additions to the plans of treatment just described.

Phrenic Nerve.—Stimulation of this nerve may be required when the diaphragm is paralyzed. One small electrode should be placed at about the middle of the neck, just in front of the sternomastoid muscle (Plate I). The other and larger electrode should be placed at the nape of the neck. A strong, slowly interrupted faradic current will usually cause contraction. If it does not, the interrupted galvanic current, the kathode over the motor point, should be used. This procedure may be used as an adjunct to artificial respiration.

Spasm of the diaphragm (*hiccough*) may be treated with the galvanic current, placing the anode on the motor point of the phrenic nerve and the other at some indifferent point. Stabile applications for at least ten minutes, which may be repeated at intervals, should be made, care being taken to increase and decrease the current strength gradually.

Facial Nerve.—Paralysis due to peripheral lesion of this nerve, known as Bell's palsy, is common. In its treatment, electricity is of great value; its use, however, should not be begun until acute symptoms have subsided, which should be at the end of a week. In the early stages, especially if DeR are well developed, the galvanic current used without interruption should be used once daily for about ten minutes. One electrode should be placed over the mastoid process and the other, preferably the kathode, over the nerve in front of the ear. As contractility returns, the muscles may be stimulated by placing one electrode over the mastoid process and the other over the motor points of the muscles supplied by the nerve (Plate I). If they will respond to faradism, either it or galvanofaradism may be employed. If not, the galvanic current must be used. The seances should be held at least every other day. Treatments should be given from three to four times weekly. At intervals of two or three weeks, if the case is long continued, a rest from treatment for a week should be given.

During the course of treatment, careful watch should be kept for the development of *secondary contractures*, which sometimes occur in the affected muscles. If such develop in any degree, electrical treatment must either be entirely suspended or an attempt may be made to diminish the spasm by placing the galvanic anode over the motor points of the muscles, the other electrode being at an indifferent point, and making stabile applications (Fig. 172, p. 115).

Spasms of the muscles supplied by the facial nerve may be treated in the same way or by the combined galvanofaradic current (p. 221).

Motor Nerves of Eye.—In paralysis of the muscles supplied by these nerves, recovery may be assisted by the use of the galvanic current. The muscles may be reached by placing the kathode over the closed eyelid as near as possible to the insertion of the muscles to be treated, and the anode at the nape of the neck. Weak currents, one to two milliamperes, should be employed. Either stabile applications for two or three

minutes are used or a few interruptions may be made. If the inferior oblique muscle is involved, it may be reached by placing a small electrode over the lower eyelid. The faradic current may also be tried, and has been recommended to be applied by means of a very small electrode directly to the muscle, the eye having previously been cocainized. It is doubtful if there is any advantage in this, just as good results being obtained by placing the electrode over the closed lids. Very weak currents and short sittings should be used. Alleman advises that if no results are obtained with the galvanic current in a week or two, the faradic by one of these methods should be tried.

Ninth Nerve (Glossopharyngeal Nerve).—The muscles forming the soft palate may be stimulated by touching them a few times with a small uncovered electrode (Fig. 115), either a rapidly interrupted faradic or a very weak galvanic current being used, as the case requires.

Tenth Nerve (Pneumogastric).—The muscles of the larynx can be best reached by placing a small electrode on each side of the organ. Either a galvanic or faradic current may be used, dependent on the cause of the paralysis. If hysterical, a rapidly interrupted faradic is preferable.

Eleventh Nerve (Spinal Accessory).—Torticollis, or spasm of the muscles supplied by this nerve, *i. e.*, the sternomastoid and upper part of the trapezius, may be treated by either the galvanic or combined galvanic and faradic currents (p. 123), the anode being placed over the muscles and the kathode at an indifferent point. It must be added that other nerves, notably the upper posterior cervical roots of the opposite side, and the muscles supplied by them (splenius capitis and rotators of the head) are involved in this condition, which is probably due in most cases to functional disturbance of their cortical centres. The condition is a most stubborn one and is infrequently cured by any means. Acute torticollis (stiff neck), which is usually due to a rheumatic inflammation of the sternomastoid muscle, may be relieved rapidly either by the use of galvanism applied as just described, by the rapidly interrupted faradic current applied to the muscle, or the local application of either the brush discharge, static wave current, high frequency effluve, or vacuum electrode (pp. 238, 245, and 249).

Fifth Nerve (Trigeminus).—The disease of this nerve which most frequently demands electrical treatment is neuralgia, either the common symptomatic form (a functional condition) or the organic disease known as tic douloureux. In the former variety much relief can often be obtained, in the latter the results are not usually satisfactory. Stabile applications of the galvanic current are usually employed, the kathode being at an indifferent point and the anode being placed successively over the tender points. A current strength of 2 to 3 milliamperes should be employed, and the application to each point should last from three to five minutes, and made at least daily, oftener if possible. Care must be taken to increase and decrease the current strength slowly. The relief of pain by this method may still further be

increased by utilizing the cataphoric action of the current and placing a solution of cocaine upon the anode. Snow strongly advises the wave current, using an electrode which will cover the face on the affected side and pressing it down firmly over the painful points. A short spark gap is first employed, which is gradually increased in length until the application becomes painful. The increase must be very gradual and the application continued for twenty minutes. The static breeze and sinusoidal currents are also used (pp. 242 and 243). In chronic cases, the secondary faradic current rapidly interrupted may be tried.

Sciatic Nerve.—Sciatica, which is usually a neuritis, is frequently benefited by the use of electricity, especially if used in connection with absolute rest. The galvanic current is preferable and is applied by placing the kathode over the sacral region and the anode stabile for about five minutes over each of the tender points. Another method is to place the anode over the sacrum and the kathode (flat electrode) at the sole of the foot and the current allowed to flow down the limb for about ten minutes. The patient should be in the recumbent position with relaxed muscles.

The static wave current is strongly advised by Snow in acute cases, an electrode of soft metal being bound along the course of the nerve. A short spark gap must be employed at first, which is very gradually increased until the patient can without great discomfort stand no more. The application should last for about twenty minutes, at the end of which period it is claimed that sedation is complete and will continue for a number of hours. The brush discharge applied to the foot and leg often gives good results and in chronic cases sparks may be beneficial, although painful at first. Excellent results may also be obtained with currents of high frequency, using a vacuum electrode along the course of the nerve. These procedures may be employed in the treatment of neuritis of other nerves.

Wullyamos[1] treats this disorder by salicylic ionization. Before the treatment the patient takes a hot bath of thirty minutes' duration to rid the pores of any fatty matter that they may contain. The electrodes are large plates of lead or block tin covered with absorbent cotton or other similar material; the cathode is saturated with 3 per cent. solution of sodium salicylate as hot as possible. Upon this the patient lies. The anode is applied either successively or at one time by divided cords to the abdomen, thigh, and leg. A current strength of 200 milliamperes for from sixty to ninety minutes is used. If the electrode burns, a layer of rubber is placed between the electrode and skin at that point.

Paralysis of the muscles supplied by the sciatic nerve or its branches is treated according to principles laid down on pages 220.

[1] Archives d'électricité Médicale Expérimentales et Cliniques. Quoted in New York Medical Journal, February 26, 1910, p. 447.

The paralyzed muscles in *multiple neuritis* from any cause should also be treated according to these rules.

Diseases of the nerves of special sense are treated under separate headings.

FUNCTIONAL AND GENERAL DISEASES

Neuralgia.—The methods of treating neuralgia by electricity have been described under diseases of the fifth and sciatic nerves (pp. 304 and 305), the principles utilized in treating neuralgia of these nerves being applicable to neuralgia of any nerve. It is to be borne in mind that electricity is not here advocated as a specific, but that its good effects are usually only to cause temporary relief from pain, while other measures as may be proper are employed to remove the cause.

Insanities.—In stuporous conditions, as stuporous melancholia, some forms of dementia præcox, and acute dementia, improvement may be obtained by the use of either static sparks or the rapidly interrupted faradic current. Measures which improve nutrition, such as static baths, currents of high frequency (p. 261), and general faradization, may be tried in melancholia. Robert Jones[1] speaks highly of the use of galvanic electric baths of a temperature of 100° F. in the depressed varieties of insanity, especially atonic stuporous conditions in young people. The bath should last from ten to thirty minutes and be continued for many weeks. Increase in weight and improvement in mental and bodily conditions resulted. In other forms of mental disease electricity is of no use.

Chorea.—Most cases of chorea yield readily to proper medical and hygienic treatment. Electricity has been much lauded by some and may be tried in obstinate cases. The proper manner of employing it is by central galvanization (p. 252) and the application of the galvanic anode to the affected limbs. Measures which improve nutrition, such as the static bath and high frequency currents (p. 261), may be tried. The wave current is said to be beneficial. Sparks applied locally do harm.

Paralysis Agitans.—Electric, as other treatment, is not very satisfactory in this disease. Such measures as improve the general nutrition and are sedative may be tried, as hydro-electric baths (p. 256) and static baths (p. 257). In a case in which there was high arterial tension, Doumer and Maes[2] obtained much relief by employing autoconduction (p. 262). Autocondensation could be employed under similar circumstances. The passage of non-interrupted galvanic currents down the limbs sometimes seems to give some relief.

Neurasthenia.—Electricity is of considerable use in the treatment of this condition. It may be employed to remove the underlying cause

[1] Journal of Nervous and Mental Disease, 1905, p. 373.

[2] Congrès International de Physiothérapie, Liège, 1905.

of the symptoms, to palliate the symptoms themselves, and as an adjuvant to other plans of treatment.

For the improvement of the weakened and irritable condition of the nervous system, daily static baths (p. 134) of five minutes' duration, and gradually prolonged as the patient becomes accustomed to them, may be used. After a while may be added the electric breeze to the head and mild sparks drawn from the body. Vigouroux, quoted by Turner,[1] claims remarkable results from this plan; in this he is supported by Turner. Rockwell recommends either general faradization or central galvanization. Currents of high frequency applied by one of the general methods described on page 261 may give good results. They should not be used if the blood pressure is low (p. 131), and if used, the seance at first should be brief (five minutes). These measures, of course, can be also employed in conjunction with other recognized plans of treatment, as hydrotherapy, rest cure, etc. The various head symptoms, as headache, feelings of pressure, tinnitus aurium, and vertigo, may frequently be relieved for a time by the use of the static breeze or spray for a few minutes. Subaural galvanization (p. 226) may also be tried for this purpose. The painful and tender spine may be treated either by stabile galvanization or by the static breeze. The static breeze to the head frequently relieves the insomnia, and for this purpose should, if possible, be given at night. Electric baths (p. 253), the water being warm, are also useful when they can be obtained. Persistent vomiting may often be relieved by using a weak galvanic current (two to three milliamperes) for about thirty minutes, the kathode being placed over the lower cervical vertebra and the anode upon the xiphoid cartilage (Jacoby). Numbness of the extremities and cyanotic condition of the same should be treated with either the dry faradic brush, friction sparks, or high frequency current with vacuum electrode. The use of faradism as a means of exercising the muscles when the so-called rest cure is being employed is described on page 252.

Hysteria.—Electricity is of great service in the treatment of hysteria. The methods for improving the general nutrition may be employed as in neurasthenia. It is also similarly employed as part of the rest treatment, a frequent plan of treatment of this neurosis.

It is, however, for its powerful suggestive influence in removing symptoms that it is of most value. Paralysis, either motor or sensory, is best treated by static sparks. If this form of current is not available, a rapidly interrupted faradic current is often efficacious. Areas of hyperesthesia (hysterogenetic zones) may be treated either by the static breeze or galvanic anode stabile.

Hysterical aphonia can be treated either by placing an electrode on each side of the larynx and employing a rapidly interrupted faradic current, or with the same form of current by placing one electrode on the neck and applying the other directly to the vocal cords.

[1] Manual of Medical Electricity, p. 280.

Contractures may be treated with the static breeze or stabile galvanization of the affected limb. The suggestive action of the applications is increased if during the application the good results which have been obtained in similar conditions are impressed upon the patient. High frequency currents, employing either the effluve or vacuum electrode, may also be of service in any of these conditions.

Exophthalmic Goitre.—The excessive action of the heart, so annoying in this disease, may frequently be lessened by the use of subaural galvanization (p. 226). Carden[1] advises the following method: "Only the galvanic current should be used. The current strength should not exceed two milliamperes, and each application should last from five to ten minutes. The anode should be placed on the nape of the neck, the centre of its lower border corresponding to the seventh cervical spinous process, and be held firmly in that position during the application. The kathode should be moved up and down the side of the neck from the mastoid process along the course of the great nerves. As this application should be made at least three times daily, patients may be taught to make it themselves. The current strength obtained from three to six cells of a dry cell galvanic battery is usually sufficient." It must be borne in mind that the resistance of the tissues is less in this disease (p. 178), consequently the E. M. F. required to produce a given current strength is not so great as in the normal individual.

Murray[2] advises the following method, which he considers most valuable: Two electrodes are fixed, one over the gland and the other at the nape of the neck, and connected with the secondary coil of the faradic battery. A weak current is thus applied for an hour or more twice daily.

In addition to the above procedure, measures to improve the general condition, as general faradization, central galvanization and static baths may be used.

Occupation Neuroses.—Electrical treatment in conjunction with other measures gives the best results in the treatment of these disorders. In the spasmodic form the anode of the galvanic current applied labile and stabile to the affected muscles, and the antagonistic muscles made to *contract* by the application of the kathode has given good results in the author's experience. The indifferent electrode, a small flat one, may be placed at the nape of the neck. The anodal application should continue for five or ten minutes, the rules for such applications in painful or spasmodic conditions being observed (p. 242). The paralytic type may be treated also with the galvanic current, the kathode being applied to the affected muscles and contractions produced. In this type also the high frequency current applied to the muscles by the effluve or vacuum electrode (p. 235) may be tried. Snow recommends the application of short static sparks (one inch) to the muscles of the forearm and hand, followed by friction sparks.

[1] Lancet, July, 1891.
[2] Lancet, November 11, 1905, p. 1379.

As there is frequently a neurasthenic basis for this condition, measures to relieve this, when it exists, are also proper. Electrical ones are detailed under the treatment of that disease on page 306.

Epilepsy.—Tracey[1] claims excellent results in the treatment of idiopathic epilepsy by the use of high frequency currents combined with *x*-rays. In some of his cases bromides were also given. His method is for the patient to receive every other day, from five to ten minutes, *x*-rays from a high tube placed six to ten inches above the head, so that the rays strike upon the anterior and occipital parts of the brain. After this the high frequency current is applied over the brain for ten minutes, and for five minutes over the spine (effluve). It is noteworthy that the cases in which the best results were obtained also were given in small doses of bromides.

[1] New York and Phila. Medical Journal, March 4, 1905, p. 422.

CHAPTER XIX

DISEASES OF THE MUSCLES AND JOINTS

Progressive Muscular Dystrophy.—The various types of this disease are treated by the application of either weak faradic or galvanic currents, or the two combined. Care must be taken not to overfatigue the muscles by having the seance too frequent, every other day for three weeks followed by a rest for a week being the proper plan.

Inflammation or Myositis.—So-called muscular rheumatism, such as acute torticollis, or stiff neck, lumbago, etc., is most successfully treated by the galvanic current. The anode may be applied stabile over the affected muscles for ten minutes once or twice daily, the kathode being at an indifferent point. The strength of the current should be from 5 to 10 milliamperes. Another and excellent method is a labile application of the anode. The author has obtained almost instantaneous relief in some cases by using the rapidly interrupted faradic current for ten or fifteen minutes. Jacoby recommends very highly the undulating faradic current. In this method a small, well-moistened electrode is placed over the thickened part of the muscle, and a weak, rapidly interrupted faradic current applied. This is then gradually increased to a certain point, then gradually decreased to the minimum; then again increased to a little stronger than the first increase, then decreased, to be again increased until a current strength is reached as strong as can be borne. The seance should last ten or fifteen minutes. This method is efficacious but painful. It may be well to use the galvanic anode, stabile as a preliminary treatment. Static sparks may also be employed.

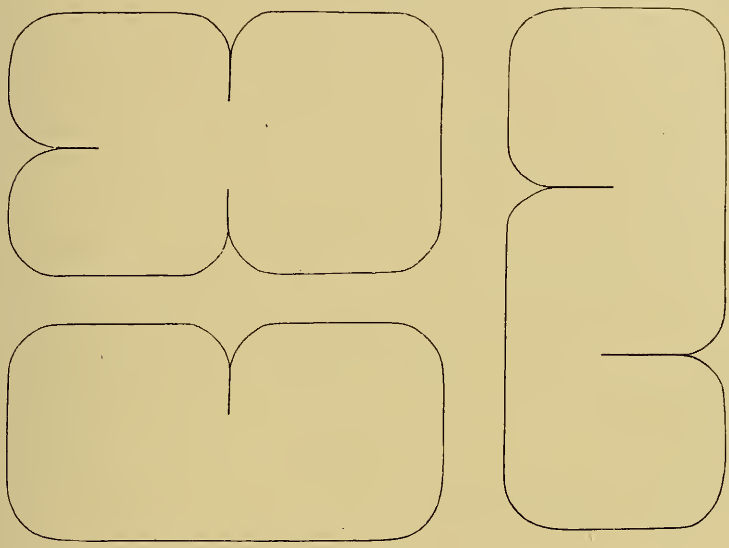
Snow recommends the static wave current (p. 259) in chronic cases of lumbago, also the brush discharge (p. 245). Local applications of the high frequency (p. 235) current may also prove useful. Similar methods may be employed in myositis due to other causes. These same methods of treatment are often of service when the muscles have been strained, as in wrenches of the back.

Diseases of the Joints.—Electricity is of much service in the treatment of these affections. *Acute sprains,* if not complicated by fracture or rupture of ligaments, may be much relieved by using the wave current (p. 259). The metal electrode (Fig. 274) should be moulded into close contact with the joint and the spark gap regulated so as to obtain as powerful a current as possible without producing muscular contractions. The application should last about fifteen minutes. Several joints may be treated at once by this method. Large electrodes should be placed over the more sensitive ones and smaller ones over those which are not so sensitive (Fig. 274). The brush discharge (p. 245) is also useful in removing tenderness and swelling. It should be applied for from

ten to twenty minutes, the electrode being constantly moved about. In obstinate cases, in stout people, or where deep structures seem to be much affected indirect static sparks (p. 227) are indicated. Acute synovitis may be treated by the same methods.

Similar measures may prove useful in relieving the pain of the inflamed joints in both *acute articular rheumatism* and *acute gout*. Snow highly recommends the brush discharge applied by rubbing the electrode rapidly over the joint for about ten minutes. High frequency

Fig. 274



Shapes in which electrodes of block tin should be cut to fit accurately about joints.

currents, either from the Tesla coil or resonator with vacuum electrode, may be similarly used. In addition to these local measures, the disease itself may be treated by promoting excretion of the products of defective metabolism with either one of the general methods of using high frequency currents (p. 261), wave current, or friction sparks applied over the entire surface of the body. The drugs and diet proper to these conditions should be employed in addition.

In *chronic inflammation* with fibrous adhesions from whatever cause much benefit can be obtained by utilizing the electrolytic *properties* of the galvanic current (p. 113). The current, as strong as can be borne, should be passed through the joint, one electrode being placed on each side of it. The application should be made daily for at least ten minutes, the electrodes being of fair size and well wetted. The absorption of exudates and fibrous tissue is thus hastened and the motility of the joint improved. The action of this current can be still further increased by taking advantage of its power to diffuse drugs (phoresis, p. 271).

It is important to remember in this connection that some drugs are diffused by the anode (cataphoresis) and others by the kathode (anaphoresis). In general it may be said that alkaline salts must be put on the positive pole, while the metallic bases, as iodine, should be placed on the negative. For the introduction of iodine, Massey advises the following method: Construct a pad of three layers of absorbent cotton covered with gauze and backed with a smaller piece of the thinnest x-ray metal. These should be sewed together. To the piece of metal the wire is attached. The pad is soaked with Lugol's solution diluted more or less with water. The application should last for fifteen or twenty minutes. When employing phoresis, the indifferent electrode may be at some remote point. Humphris[1] claims excellent results in the absorption of fibrous adhesions by introducing chlorine into the joint. His method is, when possible, to immerse the joint in a 2 per cent. solution of chloride of sodium in sterile water; an electrode is also immersed in the solution and connected with the negative pole (chlorine being electronegative) of the battery. The positive pole (a large electrode) is placed at some indifferent point. If not possible to immerse the joint, he wraps it with twenty thicknesses of absorbent lint saturated with a similar solution. A piece of pliable metal, as block tin, is then bound on to the lint covered with oiled silk protective, and connected with the negative pole. The current should be gradually increased to a point as strong as can be borne without pain and continued for thirty minutes, and done twice weekly. If abrasions of the skin are present they should be covered with collodion. If the hand or fingers are being treated, rings must be removed. Either the static wave current applied as in acute inflammation (p. 310), the brush discharge, indirect static sparks, or high frequency current with a vacuum electrode may also be used with advantage. The brush discharge is especially valuable in relieving pain. In *rheumatoid arthritis* favorable results are obtained by the use of the high frequency current (Tesla or resonator) applied with a vacuum electrode rubbed rapidly over the joint for ten or fifteen minutes until a marked hyperemia is produced, with now and then applying a few sparks, followed by the use of one of the general methods (p. 261) to secure tonic and eliminative effects. This treatment should be given from two to three times weekly. *Rhizomelique spondylosis* may also be treated by these methods. The wave current, a long electrode being placed along the spine, is very useful.

Hysterical joints are best treated with either static sparks or high frequency current, either effluve or vacuum electrode. When these are not available either the rapidly interrupted faradic or galvanic currents may be used.

If the muscles about the joints are atrophied—the so-called arthritic atrophy—they should be treated as paralyzed muscles are, with either the faradic or galvanic currents, but not until acute symptoms have subsided.

[1] Journal of Advanced Therapeutics, February, 1910, p. 67.

CHAPTER XX

DISEASES OF THE THORACIC AND ABDOMINAL ORGANS

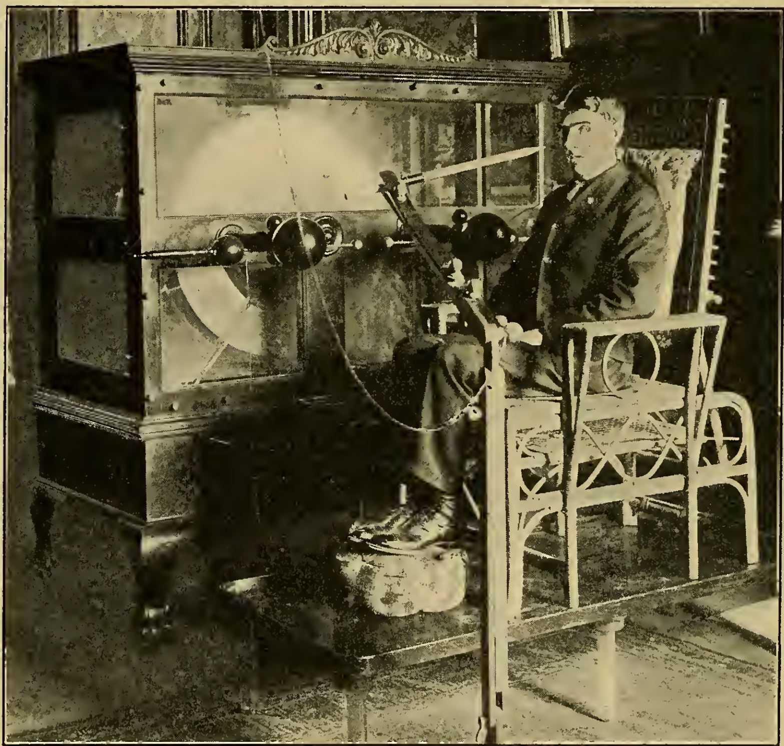
Diseases of the Lungs.—The only disease of the lungs in which benefit has been claimed by the use of electricity is *tuberculosis*.

Snow recommends the use of the static wave current associated with inhalations of ozone. The former is employed to improve the patient's general health, and the latter to kill the bacilli. The metal electrodes should be placed over the spine and abdomen and half-hour administrations given. As the discharging spark generates ozone, the patient will, of course, breathe an atmosphere impregnated with it. Ozone may also be administered by means of one of the various inhalers devised for that purpose (p. 278). Snow advises a method which he claims is as efficacious as the use of inhalers, the placing near the patient's nose of a wooden electrode ending in either a point or ball while the wave current is being administered (Fig. 275). The strength of the inhalation is varied by increasing or decreasing the distance at which the wooden electrode is placed from the nose of the patient. The ball electrode gives off the strongest discharge, which may be still more intensified by grounding it to the gas fixture. Chisholm Williams[1] has obtained good results from the employment of a high frequency current by the method of autocondensation. The daily sitting should last from ten to twenty minutes. In addition to this, the effluve may be applied locally over the affected areas, the operator's unemployed hand being placed to the back of the chest. Under this plan it was noticed that the cough and expectoration improved, weight increased, and the bacilli disappeared. It was noticed that for the first few applications the bacilli increased in numbers and the temperature became higher; pain also in the affected areas was complained of. These symptoms, however, disappeared after a few applications, and improvement was constant. He gives statistics of 43 cases treated in London by this method. Of these, 3 died: 1 of pneumonia, 1 of tuberculous kidney, and 1 of lardaceous disease. Of the remaining 40, 32 have had no treatment of any kind for eighteen months; 8 cases had, on an average, two months' treatment each since that time. The majority of them are performing their usual work. These results seem to indicate that in cases who cannot obtain the open air and forced alimentation treatment, this method should be tried. There is also no reason why it should not be used in conjunction with other methods. The introduction of drugs through the skin may also be utilized (p. 277).

[1] High Frequency Currents, p. 166 et seq.

Diseases of the Kidneys.—Rockwell[1] has published the records of 5 cases who had albumin and casts in the urine, due, he assumes, to "inflammatory affections of the tubules or stroma rather than of those more serious structural changes originating in waxy or cirrhotic kidney," which he treated with high tension faradic and static wave currents. He used flexible electrodes of block tin, 3 inches in diameter, covered with absorbent cotton, which were firmly bound over the region

Fig. 275



Static machine.

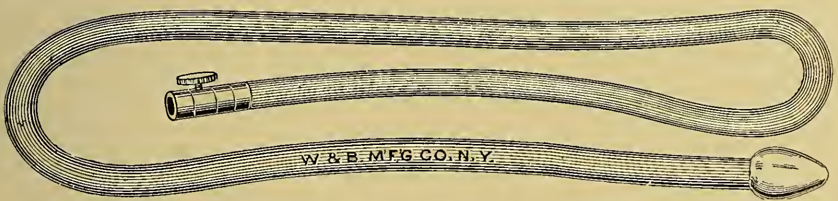
of each kidney. As strong a current as could be borne was employed for periods of time ranging from ten minutes to three-quarters of an hour, according to the susceptibility of the patient. The faradic and the static wave current were used alternately. Marked improvement resulted in all the cases. Boardman Reed[2] has treated 18 cases of albumin and casts in the urine associated with dyspeptic symptoms by the

[1] New York Medical Journal, January 18, 1902, lxxv, 104.
[2] American Medicine, November 28, 1903, vi, 865.

methods of Rockwell, and in addition he used in some of his cases the static induced current. When using this he placed one moist electrode 4 by 6 inches over the solar plexus and one $12\frac{1}{2}$ inches wide and long enough to reach from the left side of the left kidney all the way around to the front of the liver on the right side. A leather belt was placed firmly over this, and between the belt and the electrode, over the region of each kidney, was placed a pad so as to cause extra pressure of the electrode in these regions. Twenty-minute applications were made three times a week. Great improvement was obtained in 17 of the 18 cases, greater benefit being obtained, Reed thinks, in those cases in which the *static induced current* was used.

Snow recommends the use of the static wave current in Bright's disease. He employs electrodes 3 by 9 inches over the region of the kidneys, the long dimension transversely, and held firmly in position by a pillow pressed between the electrode and the back of the chair. A spark gap of from 4 to 10 inches, according to the feelings of the patient, is employed for thirty minutes daily. In interstitial nephritis with high blood pressure, one of the general methods of using high frequency currents, especially the D'Arsonval, may be tried (p. 262) as they lower blood pressure and increase elimination (pp. 131 and 135).

Fig. 276



Esophageal electrode.

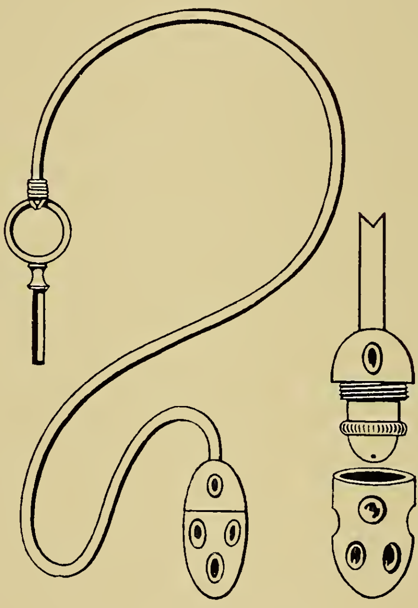
Diseases of the Liver.—Congestion of the liver from any cause may be treated and sometimes relieved by the methods described for kidney disease or by a high frequency effluve or vacuum electrode applied over the liver. The static wave current, the electrode over the liver, is useful.

Diseases of the Esophagus.—Electrolysis has been advocated by some for the relief of esophageal stricture. If employed, an electrode (Fig. 276) attached to the negative pole is introduced gently until resistance is felt from the stricture; a current of 5 milliamperes is used. Great caution should be employed, and other methods are preferred by surgeons.

Diseases of the Stomach.—Electricity may be used in diseases of the stomach to produce a *psychic effect,* to *improve motility,* or to *promote secretion.* We employ it for the first-mentioned effect in the so-called "nervous dyspepsia," meaning by this those derangements of digestive function which are seen in neurasthenia and hysteria and in which no pathological change can be demonstrated either in the walls of the stomach

or its secretions. In such cases general treatment, as either general faradization, central galvanization, hydro-electric baths, the static bath, or currents of high frequency, may be employed in conjunction with local treatment, which in all cases should be given with the patient lying on his back with the abdominal muscles relaxed. This may be carried out either by placing both electrodes on the abdomen over the stomach or by introducing one electrode into the stomach, using for this purpose Einhorn's stomach electrode (Fig. 277) and placing the other on the skin over the stomach. The former method usually answers every purpose and is more convenient. A rapidly interrupted faradic current is preferable and daily seances of about five minutes each should be given.

Fig. 277



Intragastric electrode. (Einhorn.)

In *gastralgia* of functional origin relief may sometimes be obtained by utilizing the sedative action of the anode, as in neuralgias elsewhere. A large anode being placed over the stomach and the kathode at some remote point, a current strength of from 5 to 10 milliamperes should be used. Relief may also be sometimes afforded, by using the dry faradic brush (p. 223) over the stomach as a counterirritant. Intragastric galvanization may also be tried, making the electrode within the stomach the anode. If in these cases the general health is impaired, the general methods mentioned above should be used in addition. The use of the galvanic current, the anode being introduced into the stomach by means of the Einhorn electrode (Fig. 277) and the kathode being

placed upon the epigastrium, is recommended by Ewald for nervous vomiting (see p. 317).

To "increase the motility and increase the muscle tone of the walls of the stomach, electricity may be employed in cases of *dilatation*, of *muscular atony* and of *gastroptosis*."

D. D. Stewart recommends the following method in these cases, the object being to influence the stomach indirectly by reflex stimulation and by means of the compressing action of the abdominal muscles. Either the galvanic or faradic currents may be used. If the former, the anode, a large pad (12 by 15 cm.) is fastened posteriorly over the spine, and interrupted applications of the kathode (a circular electrode having an area of about 60 sq. cm.) are made over the left hypochondrium, the epigastrium, and a greater or smaller area of the abdomen, according to the size and position of the stomach. Firm pressure should be exerted and the electrode moved from the fundus toward the pylorus, with occasional rests in various positions. The current strength is gradually increased, according to the tolerance of the patient, from 10 to 30 milliamperes and active contraction of the abdominal muscles must be induced. The maximum strength should be employed for from ten to twenty minutes, after which the current strength is gradually diminished to zero. Applications may be made daily or less frequently according to the effect.

Stewart recommends that the current interruptions be made by means of an automatic attachment upon the switchboard (Fig. 174) at the rate of sixty per minute, but the treatment can be carried out without this. Either the rapidly interrupted faradic current, the interruptions being produced by lifting the active electrode (p. 222) or the sinusoidal current, may be employed in the same way.

Another plan of treatment is to place one electrode over the left hypochondrium and the other over the stomach, and either strong faradic or sinusoidal currents used. Einhorn recommends direct faradization by the introduction of his electrode (Fig. 277) into the stomach, the other being placed on the abdominal wall.

Ewald[1] states that either by this method or by placing both electrodes over the stomach externally the passage of the stomach contents into the intestines is materially hastened. To cause marked increase of peristalsis he advises placing one electrode in the stomach and the other in the rectum.

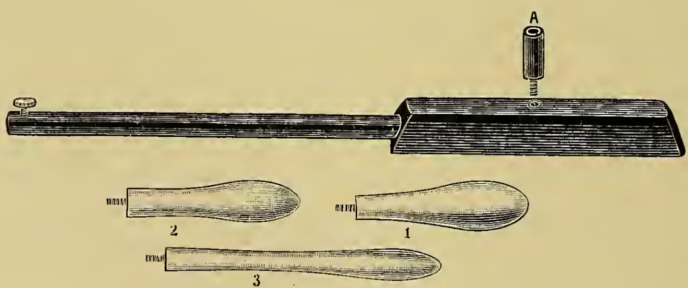
Chisholm Williams[2] reports good results in cases of *atonic dilatation of the stomach* from the use of currents of high frequency. He employed autocondensation for ten minutes and the local effluve over the stomach for five minutes daily for six weeks. He also quotes a report of Drs. Alexander Crombie and T. J. Bokenham, who treated 17 cases with excellent results. To *increase secretion*, electricity may be employed in cases where there is either subacidity or diminished secretion.

[1] Ewald. Diseases of the Stomach, first American edition, p. 157.

[2] High Frequency Currents, p. 175.

Intragastric faradization by means of the Einhorn electrode (Fig. 277) is the preferable plan of treatment, although the galvanic current, the kathode being within the stomach, may be used. The application should be made when the stomach is empty, either before breakfast or as long as possible after the preceding meal, which should be light. If it is a case of gastric catarrh in which there is much secretion of mucus, lavage should be practised first, after which, before the electrode is introduced, from one-half to a pint of warm clear water should be swallowed and allowed to remain (this should be done whether lavage is employed or not). Before introducing the electrode, which is done in a similar manner to the introduction of the stomach tube, the covering of the metallic end of the electrode should be unscrewed and the metal covered with a thin layer of absorbent cotton. The current should be increased and decreased gradually; if the galvanic is employed the strength should be from 5 to 8 milliamperes; if the faradic, a rapidly interrupted, strong enough to cause contraction of the abdominal muscles, should be used. Daily seances of from fifteen to thirty minutes' duration should be given for about four weeks. In cases of gastric catarrh the application may increase the secretion of mucus, and in such it is well to follow it with lavage. Leullier[1] has reviewed this question and confirms the favorable results claimed by these methods especially in atonic conditions. He advocates that one electrode be within the stomach.

Fig. 278



Set of rectal electrodes: *A*, vulcanite section for relieving anal contraction. 1, short rectal; 2, constipation electrode, to be used without insulated portion; 3, long electrode.

Diseases of the Intestines.—*Chronic constipation* due to atony of the muscular coat of the intestines from whatever cause is the intestinal condition most frequently subjected to electrical treatment. Both electrodes may be placed externally on the abdominal walls, or one may be placed there and the other (Fig. 278) introduced into the rectum. Either the faradic or sinusoidal currents are the preferable ones to employ, but the galvanic, the kathode being within the rectum if that

[1] Journal of Advanced Therapeutics, March, 1906, p. 155.

method is used, and galvanofaradic may also be employed. In intrarectal galvanic applications weak currents must be used. Dr. Sigismund Cohn[1] advises the use of either the wave or static induced current, the former in the milder, the latter in the obstinate cases of long standing. The positive pole should be in contact with the patient. If the wave current is used, the patient is in contact with one pole, the other being grounded or not, the latter being the case when the treatment is desired to be mild.

The electrode may either be introduced into the rectum (Fig. 278) or placed on the abdomen, a tinfoil plate 8 by 10 being then used. The strength of current is regulated by the length of the spark gap (p. 261). If the static induced curent is used, one electrode is placed on the abdomen; the other may be either placed on the back or introduced into the rectum (Fig. 278). The action of these currents may be increased by causing an undulating effect, *i. e.*, gradually increasing to the maximum strength, then gradually decreasing to zero, and repeating this a number of times.

Similar methods may be employed for *meteorism.*

Intestinal obstruction and *postoperative paralysis of the bowel* have been treated successfully by Dieffenbach[2] by the following method:

1. The nurse prepares the bed with rubber sheets and padding to prevent wetting the mattress, and a flat and long bed pan is placed under the patient.

2. Previous to the operation it is well to perform lavage of the stomach with a quart of saline solution of half normal strength.

3. Three or four quarts of saline solution of half normal strength at a temperature of 105° to 110° F. are kept ready.

4. The rectal electrode has attached to the distal end the cord or rheophore connected with the negative pole of the galvanic battery and the central orifice of the electrode connects with a Davidson syringe. The electrode is introduced into the rectum as far as it will go, and one quart of the saline solution is slowly injected.

5. A large flat covered electrode (4 x 6 inches), well moistened, is connected with the positive pole and placed over the right hypogastrium so as to cover the ascending colon. An assistant should make firm and even pressure upon it and keep it moist. This electrode may be also shifted to either the transverse or descending colon.

6. The current is gradually increased until 10 to 15 milliamperes is registered, and allowed to remain so for three minutes to cause liberation of chlorine ions; the polarity is then reversed. This reversal is continued every thirty seconds for from five to ten minutes. If a desire for evacuation is felt, the electrode is removed. If a satisfactory movement is obtained, no further treatment is necessary; otherwise more fluid is injected as before and a rapidly interrupted faradic cur-

[1] New York Medical Journal, September 6, 1902.

[2] Journal of the American Medical Association, April 1, 1911, p. 958.

rent as strong as can be borne used for five minutes. This is usually successful, but in some cases the operation may have to be repeated several times at intervals of about three hours.

7. After the electric treatment, the head of the bed should be elevated, so that the patient is in an inclined position of from 25 to 45 degrees, and hot normal saline enemas (one quart, 105° to 110° F.) given every two hours until normal conditions supervene.

This method is asserted to have been successful in *chronic constipation with impaction of feces; atony of the bowel; traumatic, localized and general peritonitis with statis,* intestinal torpor after shock, slight volvulus or kinks in the bowel after prolonged manipulation, and chilling of the bowel following laparotomies; intestinal paralysis after prolonged meteorism, intestinal paralysis following various forms of hernia. It has not been successful in intussusception and cases of obstruction due to organic lesions of different kinds.

Webb[1] has treated inflammatory conditions of the lower bowel by means of ionization, employing a solution of sulphate of zinc.

Diseases of the Rectum.—*Stricture of the rectum* has been treated by electrolysis. The method used is similar to that for stricture of the esophagus (p 315). Other methods will probably be more satisfactory.

Hemorrhoids. When the tumors are indurated, electrolysis can be employed, the negative pole in the shape of a platinum-iridium needle being inserted into each hemorrhoid and using a current strong enough to blanch it. Patterson[2] advises that, following this, a moist copper electrode, as the anode, be introduced into the rectum and a current strength of 10 to 15 milliamperes used daily for about ten minutes. He attributes part of his success with this treatment to the anodal diffusion of oxychloride of copper (p. 391), and has devised an electrode for the purpose. Zinc-mercury cataphoresis (p. 391) has also been advised, using zinc electrodes, one to two inches long.

Cocaine anesthesia is employed; the indifferent electrode may be wet with a 1 per cent. solution of soda; a current of about 25 milliamperes is used for about twenty minutes. After the treatment an opium suppository should be inserted.

The static wave current may be employed very much as described for chronic constipation (p. 319), and in addition an electrode may be placed over the liver (p. 315) to relieve the congestion that is frequently present in that organ. High frequency currents with vacuum electrodes introduced into the rectum (p. 238) (Fig. 197) may also prove of service. Clark (p. 270) claims that his method (desiccation) has been successful. The high frequency current similarly used has been advised in *fissure of the anus.*

Condict[3] claims to have obtained excellent results with the static wave current in *enlarged spleens* secondary to malaria. The electrode is bound over the organ and connected with the positive pole.

[1] Lancet, April 22, 1911. [2] Journal of Advanced Therapeutics, March, 1907, p. 142.
[3] Journal of Advanced Therapeutics, September, 1907, p. 461.

CHAPTER XXI

DISEASES OF THE BLOODVESSELS

Aneurysm.—The treatment of saccular aneurysm of either the abdominal or thoracic aorta by what is known as the Moore-Corradi method gives, at least in those of the thoracic aorta, better results than any other method. The method consists in introducing through a hollow needle a fine wire which is coiled within the sac, as suggested by Moore in 1864, and then passing a strong galvanic current through this wire, as advised by Corradi in 1879. To D. D. Stewart, of Philadelphia, belongs the credit of showing the possibilities of the operation and perfecting its technique.[1] The method is only applicable when the aneurysm is *saccular*, and when situated in the abdominal aorta a preliminary abdominal section is necessary to expose it.

The technique as advised by Stewart is as follows: The needle preferred is, of course, hollow, made of gold and insulated to within one-quarter of an inch of its tip with porcelain (shellac may also be used). This is introduced under antiseptic precautions into the sac, where it is nearest the surface and away from its mouth; then through it, with the same precautions, is introduced a fine coiled wire of either silver, platinum, or gold,[2] of about 30 gauge and so drawn that it will assume snarled, spiral coils. The amount required depends upon the size of the sac, viz., for one of about three inches in diameter, three to five feet is sufficient; for a diameter of four or five inches, eight to ten feet should be used. The end of the wire is then attached to the *positive* pole of the galvanic battery and the negative, in the shape of a large clay pad (p. 194), or the largest one shown in Fig. 150, placed on the abdomen. The current strength is then gradually increased until it reaches from 50 to 100 milliamperes, which must be maintained for an hour or longer and then gradually decreased to zero.[3] The wire is then detached from the battery, the needle carefully withdrawn by rotation and counterpressure, and the released external portion of the wire gently pulled upon and cut close to the skin, the cut end being pushed beneath the surface. This latter procedure may be facilitated

[1] For the literature of the subject see D. D. Stewart, American Journal of Medical Sciences, October, 1892; ibid., August, 1896; Phila. Medical Journal, November 12, 1898; Guy Hunner, Johns Hopkins Medical Bulletin, November, 1900; Freeman, Transactions of American Surgical Association, 1901, p. 359; Matas, Transactions of Southern Surgical and Gynecological Association, 1900, p. 286.

[2] Stewart prefers gold.

[3] If there be more than one point of bulging, and it is suspected that a very large or multilocular sac is being dealt with, it is well to insert several needles and pass wires through each, which are all attached to the positive pole.

by drawing the skin at the site of the puncture slightly to one side when introducing the needle. The opening is then sealed with gauze and collodion. When operating on thoracic aneurysms the skin, if desired, may be rendered anesthetic before the puncture with cocaine or ethyl chloride. Of course, the source of current should be carefully tested first to see that everything is working properly.

Freeman (*loc. cit.*), while he did not do so in his cases, thinks that possibly a large amount of wire (100 feet or more) may be preferable. He employed a soft, undrawn, unalloyed silver wire, devoid of spring, which he thinks is preferable to the hard, highly drawn wire, which is full of spring. He directs that the cannula through which the wire is introduced should be inserted just within the sac and no farther. Hunner (*loc. cit.*) gives the following directions: The needle should be either the trocar and cannula or the lance-pointed aspirator needle; the tube should be large enough for the easy passage of the wire, and insulated to within 1 cm. of the point with a non-conducting material, that which he found best for the purpose being the "Best French Lacquer," made by Behlen & Bro., of New York. Needles insulated with this must be sterilized by placing them, after they are lacquered, in a test-tube, which is then corked with cotton and placed in a hot-air chamber. The temperature is raised to 160° C. and kept so for one hour. The test-tube should be kept corked until the time for the operation, when the needles are emptied out on a dry sterile towel or plate. The wire used by him was a silver alloy (75 parts of copper to 1000) drawn from No. 8 to No. 27 standard gauge. The spools of wire should be boiled for fifteen minutes before using. Hunner differs from most operators in thinking that a current strength of 20 milliamperes is sufficient. The dangers to be expected are sepsis; the development and rupture, especially in large multilocular aneurysms, of a secondary sac due to rapid filling of the main sac by coagulum and the shunting of the blood stream against a portion not receiving a special strain before; emboli breaking from the sac wall during or after the insertion of the wire; in abdominal aneurysms the closing of important vessels by these being suddenly filled with clot.

The results of the operation as given by Hunner in 23 cases, 17 thoracic and 6 abdominal, are: 4 were cured; of these, 3 were thoracic, 1 abdominal. In 9 cases there was relief of the symptoms and prolongation of life. To these should be added Freeman's 2 cases, in 1 of which there was great relief, in the other probable cure, and Willard's case, in which there was relief.

Varicose Veins.—These have been treated by electrolysis in a similar manner to that just described for aneurysm, a needle attached to the positive pole being introduced into the vessel. A current strength of from five to ten milliamperes is sufficient.

Arteriosclerosis.—Arteriosclerosis or arteriocapillary fibrosis is frequently accompanied by greatly increased blood pressure. Hypertension may also occur primarily, due to toxic conditions, especially

gout and nephritis, which when long continued causes arteriosclerosis. In such cases especially a lowering of the pressure to near the normal limit is important. It must not be forgotten that in certain cases an increased tension is compensatory, it being due to the effort of forcing the blood through the rigid and narrowed vessels. In these, therefore, in which there is some hypertrophy of the left side of the heart and freedom from symptoms, the pressure should not be diminished unless excessive. As a means of reducing blood pressure, high frequency currents are useful (p. 131) in connection with other recognized therapeutic measures. For this purpose the D'Arsonval current, administered by either autocondensation or autoconduction, is preferable; if the former method is used the patient should, by choice, receive the current through the hands, and many authorities believe it more efficacious for this purpose if the supplying current is from a static machine (p. 261). The amount of current used should be measured by a meter (Fig. 167). From 400 to 600 milliamperes should be employed for from ten to fifteen minutes. As a rule, this will cause a marked lowering without cardiac depression (pp. 135 and 219).

When interstitial nephritis exists, if advanced, the treatment should be used with great care. When parenchymatous nephritis is present, the static wave current, the electrodes being over the kidneys (p. 259), with hot air or electric light baths (p. 282) is preferable.[1]

Raynaud's Disease.—In the milder forms of this disease, which are probably due to spasm of the small vessels, electricity will often prove useful. Barlow's method has given satisfactory results; it is as follows: Immerse the extremity of the affected limb in a basin containing salt and tepid water; one pole, preferably the kathode, as it dilates vessels (p. 267), of a galvanic current should be immersed in the water, and the other placed at some indifferent point, as the upper part of the limb. The current should be as strong as can be borne and the circuit may be broken at intervals. It is also advised to keep the fingers or toes, as the case may be, in motion during the treatment, which should occupy about ten minutes daily. An objection is that it often causes severe pain.

Either the high frequency effluve or vacuum electrode, as they dilate vessels, may also give relief, especially when local syncope exists. The procedures may also be tried in those cases in which there is actual disease of the vessels, termed by Buerger *thrombo-angiitis obliterans*.[2] The author has obtained relief in the various forms of acroparesthesia, especially the numbness of the hands which elderly people with arteriosclerosis complain of, both with the high frequency current, using a vacuum electrode and the galvanic current, applying the kathode labile over the hands (see also pp. 284 and 300).

Phlebitis.—Phlebitis may be relieved by the use of radiant light and heat (p. 284) and the static brush discharge (p. 245) over the inflamed area.

[1] Journal of Advanced Therapeutics, April, 1908, p. 207; ibid., June, 1909, p. 280 et seq.
[2] American Journal of the Medical Sciences, October, 1908.

CHAPTER XXII

DISEASES OF THE EYE

The use of electricity has proved of much service in many diseases of the eye and its appendages. The galvanic current is most generally useful; in some, however, the high frequency current is of service.[1] The electrocautery is also employed. S. Lewis Ziegler,[2] who has had much experience, advises that all the apparatus be carefully adjusted to measure most accurately the therapeutic currents employed. Therefore, when using the constant current, a milliamperemeter (Fig. 46) must be in the circuit, and it is well to have one which has a secondary scale graduated from 1 to 5 milliamperes. He believes that the best results are obtained when there is a high E. M. F. (sixty to seventy volts) controlled down to a low amperage ($\frac{1}{2}$ to 1 milliampere). If a higher amperage is used, a lower voltage must be employed, (which can be obtained by having less resistance in the current controller), as currents from a higher voltage are very painful to the eye. If a battery is used, fifty or sixty cells will be needed to secure the required strength. If the street current is employed, a volt controller on the shunt principle is necessary, as well as a carbon rheostat (Fig. 105) to control the amperage. The electrodes must be well constructed and watched for possible defects occurring while in use. Ziegler in most cases uses electrodes such as are shown in Figs. 279 and 280, which have a long handle that can be held by the patient. The curved metal eye piece is either covered with platinum foil or gold plated. Zeigler prefers the gold plating. The metal plates must be covered with moist absorbent cotton and placed over the closed lids. The indifferent electrode should be a flat sponge-covered electrode, 2 by 3 inches, placed at the back of the neck. This may be held in place by the patient's collar.

When the application is to be made directly to the cornea or sclera, an electrode such as is shown in Fig. 281 is convenient. This consists of a small bar of silver insulated by a hard rubber shell, save at its lower extremity, which is seven millimeters in diameter. The tip is screwed into a collar which is attached to a coil of insulated wire, which acts as a spring, hence breaks the force of the impact upon the sensitive cornea or sclera. The current usually must be turned on and off gradually, and under no circumstances should it be reversed while in contact with the patient, otherwise serious results might ensue. In some

[1] L. Webster Fox, Journal of Advanced Therapeutics, April, 1907, p. 169.
[2] Journal of Advanced Therapeutics, May, 1907, p. 228.

cases for stimulation, either the combined galvanic and faradic or sinusoidal currents may be used. Treatment may be given either daily or every other day for from ten to twenty minutes, and 1 milliampere reduced to $\frac{1}{2}$ a milliampere is the strength usually employed. By its

Fig. 279

Single eye electrode.

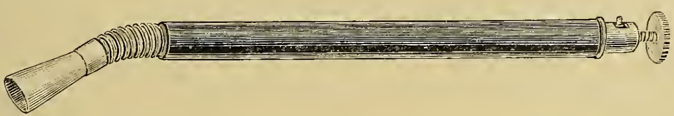
electrolytic and phoretic action (pp. 113 and 114) the current causes absorption of morbid exudates; when stimulation is desired the stimulating property of the negative pole is utilized (katelectrotonus), and when sedative action is desired the positive pole is used (anelectrotonus)

Fig. 280

Double eye electrode.

(p. 115). Therefore, in all inflammatory conditions, as plastic iritis, spongy iritis, iridocyclitis, choroiditis, or neuritis. the positive pole should be applied over the eye. An exception to this rule is in glaucoma, where the negative pole should be employed. In long-standing intra-

Fig. 281



Electrode for direct application to the cornea or sclera. (Alleman.)

ocular hemorrhage and vitreous opacities absorption is hastened by the positive pole.[1] In optic atrophy and toxic amblyopia the negative pole is indicated. In atrophy accompanying spinal cord disease the

[1] In some cases the negative pole does better. Either may be tried (see p. 328).

results are not so good as in that due to other causes. In these cases care must be taken not to overstimulate; therefore the seance should be short (five to ten minutes).

Cataphoresis (p. 271) has been used to obtain cocaine anesthesia for operative purposes. A 20 per cent. solution should be used for twenty minutes. By this means enucleation has been performed without pain. Electrolysis is used to destroy diseased tissue, as in pterygium, trachoma, and to remove hairs, the cautery used in certain cases of corneal ulcer, pannus, ectropion, and entropion.[1]

When high frequency currents are indicated, a vacuum electrode, similar in design to Fig. 280, may be used. Either the Tesla or resonator current may be employed, treatment being given daily for from two to twenty minutes. The current must be mild.

Diseases of the Retina and Optic Nerve.—In *hemorrhagic retinitis* the galvanic current may be of service in promoting the absorption of the blood. Alleman[2] especially recommends its use in diabetic retinitis with or without a central scotoma. He used a current of 1 to $1\frac{1}{2}$ milliamperes in strength, the kathode being placed over the eye, the anode at an indifferent point. This was done for five minutes two or three times a week. In several cases he has seen a diminution or disappearance of the scotoma and a marked improvement in vision. In albuminuric retinitis the results have not been so satisfactory.

Electricity seems to be the only method of treatment that has been of any service in *retinitis pigmentosa*. A number of cases have been reported by competent observers[3] in which the galvanic current produced considerable improvement. The method employed by Gunn was to place the anode over the closed lid of one eye and the kathode either over the opposite eye or the temple. The current was gradually increased until a flash of light was seen by the patient on opening and closing the circuit. The kathode was next moved about on the nape of the neck, mastoid and supra-orbital regions to determine which point gave the most marked light sensations to the patient. When this point was determined it was kept there for a half-minute, removed, then reapplied. It was next applied to a corresponding point in the opposite side of the head, and then over the closed eyelid of the same side.

Then both poles were removed and reapplied, with the anode placed where the kathode and the kathode where the anode had been, the sitting lasting from five to eight minutes. The method used by Derby and Standish is simpler. In some cases they applied the electrodes on each temple, in others the anode was placed over the closed eye and the kathode on the brow or temple. Each sitting lasted five minutes and was repeated in some cases three times weekly, in others every five days for a number of months. In the cases reported the vision improved,

[1] Special directions will be given in the discussion of the individual treatment of the different diseases.

[2] International System of Electrotherapeutics, second edition, p. G. 15.

[3] Ibid., p. G. 16, and Transactions of the American Ophthalmological Society, iv, 217, 553.

the fields increased in size, and the pigment patches became less characteristic in appearance. Ziegler[1] recommends the anode over the eyes, changing it to the kathode from time to time. He also advises the sinusoidal current. The indifferent electrode should be on the nape of the neck.

In *optic neuritis* and hyperesthesia of the retina, Ziegler, of Philadelphia, has obtained excellent results with currents of $\frac{1}{2}$ milliampère for ten minutes gradually increased to one milliampere for ten minutes more, the anode being placed over the closed eye and the kathode on the nape of the neck. The sittings should be at least three times weekly. In the early congestive stage of an optic neuritis benefit has been claimed from high frequency currents. An electrode such as shown in Fig. 280 may be used by placing it firmly over the closed eyelids. Ziegler has also obtained good results in *optic atrophy* when not accompanying spinal cord disease, the same method as in neuritis being used, excepting that the kathode is placed over the eyes. Erb recommends a similar method, and in addition places an electrode on each temple for several minutes, so that the current passes transversely. He also reverses the current several times, and he obtained the best results in those cases which followed neuritis. Mr. Marcus Gunn obtained the following results in the treatment of 18 cases of atrophy: 6 were improved, 4 received doubtful benefit, and in 8 no good results were obtained; 2 of the 6 cases which at first were improved subsequently relapsed and were not a second time favorably influenced by the treatment. Charles Stedman Bull, after treating a large number of cases, has been unable to see any good resulting from the electrical treatment of either neuritis or atrophy, and it is proper to state that this is the opinion of many more observers. In such a hopeless condition it is, however, worth a trial.

In *detachment of the retina*, Stillson[2] has reported five cases in which he made multiple punctures of the sclerotic with the galvanocautery, with four recoveries continuing from one to three years. He made one puncture under the most prominent part of the detachment, and a second at some little distance from this near the edge of the detachment. After the cautery tip had passed into the subretinal space, it was then held there for a moment until it burned a round hole, which would not close as rapidly as an incision made with a knife. After the operation the patient should be put to bed with the eyes bandaged and the usual medicinal treatment given. A cautery similar to that employed for corneal ulcers (Fig. 283) can be used for this operation. Fox (*loc. cit.*) obtained improvement in three cases by the employment of the high frequency current.

Hemorrhagic effusions into the eyes may be hastened in their removal by the use of the galvanic current, the anode being placed over the

[1] Personal communication.

[2] American Journal of Ophthalmology, May, 1898.

closed lid and the current, about 1 milliampere, allowed to pass for from five to ten minutes daily.

Toxic amblyopia is benefited by the use of the galvanic current, as recommended for optic atrophy. In *amblyopia exanopsia*, Coover[1] obtained excellent results from the use of high frequency currents. Similar results have also been obtained by Fox (loc. cit.).

Diseases of the Iris.—In some cases of *acute iritis* pain may be relieved by placing the anode over the closed lid and employing a current of one milliampere in strength for two or three minutes. In removing the results of an iritis, *i. e.*, the adhesions and inflammatory exudates, more certain results are obtained. In these cases a current of 1 milliampere in strength is employed for ten minutes, the kathode being placed over the closed lids. Satisfactory results have been obtained by Alleman[2] in clearing up *hemorrhage* from the *iris* by using a galvanic current of a strength of from 1 to 1½ milliamperes, the kathode over the closed lids.

Diseases of the Vitreous.—Both the galvanic and faradic currents have been used to clear up opacities of the vitreous. Various methods of making the application have been recommended by different observers, all with asserted good results.

Girard Teulon advises placing the anode on the closed lids and the kathode on the neck, using a weak current for from two to four minutes. Ziegler advises practically the same method, but gives a ten-minute seance. Little[3] claims that better results are obtained from the faradic current. He advises that the applications be made every other day with a weak rapidly interrupted current, one pole being over the eye and the other either held in the hand or placed on the nape of the neck. He states that two or three weeks' treatment are usually sufficient, and that the treatment is indicated in opacities produced by any cause, although his cases were confined to those due to changes in the choroidal or retinal circulation. He suggests its use in opacities due to the presence of a foreign body, and believes that it is possible by this method to clear up the vitreous so as to locate it.

Diseases of the Sclerotic.—Alleman[4] states that in *episcleritis* he has seen the pain relieved and a favorable outcome hastened by the use of the galvanic current. He has used it both by placing the electrode on the closed lid and directly on the sclera, but he prefers the latter method. The anode should be placed on the eye and the current strength gradually increased from 1 to 1½ milliamperes for three minutes. If the electrode is placed directly upon the eye, such a one as is shown in Fig. 281 should be used.

Diseases of the Cornea.—The use of the galvanic current has been advocated by Benson in cases of *strumous keratitis*, for the relief of the

[1] New York Medical Journal, October 14, 1905, p. 800.
[2] International System of Electrotherapeutics, second edition, p. G. 14.
[3] Transactions of the American Ophthalmological Society, 1882, p. 360.
[4] International System of Electrotherapeutics, second edition, p. G. 14.

photophobia. His method is to place the kathode on the supra-orbital foramen and the anode on the face. Alleman[1] has also in a few cases obtained marked relief of the pain and blepharospasm by employing in a similar way for five minutes a galvanic current of 1½ milliamperes in strength. Erb[2] states that in one case of beginning neuroparalytic keratitis and conjunctivitis due to paresis of the left trigeminus he observed decided benefit from galvanic applications to the eye, the kathode being applied both labile and stabile over the closed lids.

Both the galvanic and faradic currents have been tried in the treatment of *corneal opacities*. Alleman[3] has treated a large number of these cases with the galvanic current, and has obtained very encouraging results. He states that the secret of success "is in producing sufficient stimulation of the scar to bring about its gradual absorption and the deposit of clear corneal tissue, and in stopping just short of an irritation which shall produce active inflammatory conditions with stasis and a destruction of tissue." In making the application he advises that the operator stand behind the patient, who should be seated in a reclining chair, with the head thrown back. The anode is placed on the cheek of the same side as the eye that is to be treated, and the kathode placed on the tongue; the current is then gradually increased until the needle of the meter indicates the strength of current that it is desired to use, *i. e.*, about ½ to 1 milliampere. The object of this is to be sure that the meter is registering correctly, the tongue offering about the same resistance as the eye, hence the patient would know by the pain experienced if the current was too strong. After this is done, the cornea should be anesthetized by the instillation of either cocaine or eucaine and the electrode (kathode) (Fig. 281) placed upon the opacity. The current controller should be in the hands of an assistant, who should carefully watch the milliamperemeter so that a uniform strength of current be maintained. The eyelids should be held apart by the thumb and forefinger of the operator's left hand, so that they do not come in contact with the electrode. The proper strength of current varies in different cases. It is usual to begin treatment with ½ to 1 milliampere for one minute; if this is well borne, the time may be gradually increased to three or four minutes, also at each successive sitting slightly increasing the current strength, until the point of tolerance is reached, which is indicated by slight symptoms of irritation. These should subside before the next application, which is usually made after an interval of one day. Four milliamperes have been borne in exceptional cases, but from one to one and one-quarter is the average.

The age of the opacity seems to have no influence upon the prognosis, excepting that recent cases do not progress as favorably, being more prone to severe inflammatory reaction. Dense white scars yield slowly, while the improvement in superficial opacities is rapid. In cases of adherent *leukomata* with dense scars the centre of the scar

[1] International System of Electrotherapeutics, second edition, p. G. 10.

[2] Handbook of Electrotherapeutics, p. 307.

[3] Loc. cit., p. G. 11.

will require a longer time for its absorption, and it is not always advisable to continue treatment until all opacity disappears. The clearing away always begins at the margin of the scar. During the application the conjunctiva becomes congested and fine vessels are often seen running on to the opaque area. These disappear soon after the application; their presence, however, is a favorable sign, and the progress of the case can be followed by noting the lessening area of the unvascularized scar.

Ulcers of the cornea may be benefited by the soft administration of the brush discharge from a pointed terminal (p. 245). It has been claimed that the resultant opacity will be less than by any other method. Traumatisms of the corneal conjunctiva may be also treated by this method, healing being stimulated thereby.

The galvanocautery affords the preferable means of cauterizing the cornea, which may be required in *corneal suppuration* that is rapidly spreading or cannot be checked by milder measures; *chronic ulcers* which will not heal under other treatment; and the making of an aseptic opening of the anterior chamber in *conic cornea*. The following directions for the operation are given by Dr. Edward Jackson:[1] "The cautery tip should be of platinum and quite small—one that can be heated by a storage battery of one or two good cells. The handle should be light and furnished with means for readily making and breaking the circuit (Fig. 304). The conductors should be so supported as not to drag on the handle or to interfere with the sureness and accuracy of the surgeon's touch. The area to be burnt should be mapped out carefully. This may be done with a solution of fluorescin or with toluidin blue.

"The eye is placed under the influence of either cocaine or holocain, and first touched with the unheated tip, to reassure the patient and secure his steadiness. Then, as the tip is again brought near the eye, the circuit is made; and when a white heat is attained the parts to be destroyed are touched lightly or more firmly, according to the depth of tissue to be affected. If much tissue is to be destroyed it is best to make a number of brief contacts, withdrawing the tip between them, so as not to cause the moderate heating of the neighboring parts, which alone is painful. For suppurating ulcer the application may be repeated whenever it is discovered that new tissue is being invaded. For other ulcers the burn should be quite sufficient."

The indications for the use of the cautery are all sloughing ulcers which fail to show improvement after milder measures have been tried; in torpid or relapsing ulcers, when a decided stimulant is needed; in certain types of infecting ulcers of serpiginous character; in annular ulcer and the furrow keratitis, and in rodent ulcer.

Ziegler (*loc. cit.*), in cases of confirmed *pannus*, advises "burning a small groove around the cornea at the sclerocorneal junction, thus cutting through the vascular network and permanently checking the corneal invasion by forming a cicatricial bank in the line of the eschar.

[1] Electrotherapy, Jacoby, p. 235.

This procedure is equally efficient in cutting of a single leash of vessels that sometimes persist in spite of the usual treatment."

Powder grains embedded in the cornea which cannot be scrubbed off should be removed with the galvanocautery, a similar apparatus to that described above being used. The operation should be performed early, else the charcoal in the grain becomes diffused and causes disfigurement. If the grains are numerous, general anesthesia by means of chloroform should be employed. The seat of each grain should be then touched with the white-hot point, long enough to produce a slough that will include the whole grain. A large number of grains can be thus treated at one operation. The reaction is not severe and healing is rapid after the separation of the slough. The resultant scars are slight. If any grains remain after the first operation it should be repeated as soon as possible.

Pterygium has been treated by electrolysis as follows: The growth, including the bloodvessels, is caught up with a rat-tooth forceps which is attached to the negative pole of a galvanic battery. A current of from three to five milliamperes is employed until the vessels turn white.[1]

Diseases of the Lens.—No results have been obtained from the use of electricity in cataract.

Diseases of the Lids and Conjunctiva.—One of the valuable measures for the treatment of *granular conjunctivitis* or *trachoma* is electrolysis. Two different plans have been advocated. Meyers[2] destroys the granulations by puncturing them with a fine needle and destroying their nutrient vessels. According to Meyers the indications to be met are first to remove from the tissues the microörganisms which produce the morbid condition without permanent injury to the normal conjunctiva, and secondly, to relieve the excessive nutrition which, even after the microorganisms have been destroyed, keeps the lid in an abnormal condition. His method is to first anesthetize the lid with cocaine solution, then, the lid being everted, each granulation is punctured as near as possible to its nutrient vessels with a delicate platinum or iridoplatinum needle, which is attached to the kathode of the battery, the anode being at some indifferent point. Currents of from $1\frac{1}{2}$ to 2 milliamperes are used. After the use of the needle the coagulum should be washed away with a saturated solution of boric acid. Jackson[3] states that this method is not applicable where the swelling is great and the number of granulations many, but for the destruction of isolated trachoma granules this is probably preferable to any other treatment. Johnson's method consists of a combination of scarification and electrolysis, and is applicable before cicatricial changes have occurred. The patient is first thoroughly anesthetized with a general anesthetic, then the lid is inverted over a hard rubber spatula, and the conjunctiva, held firmly by a hook, is put tightly on the stretch. A three-bladed scarifier is then, with a finger motion, drawn along parallel to the margin of the lids,

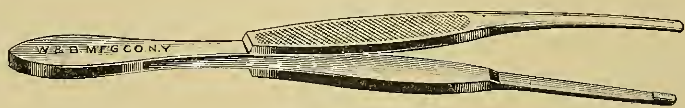
[1] J. H. Davis, quoted in Journal of Advanced Therapeutics, August, 1909, p. 389.

[2] Ophthalmic Record, January, 1900, p. 9.

[3] Electrotherapy, Jacoby, ii, 233.

care being taken to make the incisions sufficiently deep at the extremities of the cut. With the last cut as a guide, parallel incisions are then made as far as possible toward the retrotarsal fold. The depth of these incisions should be from two to four millimeters, according to the thickness and engorgement of the parts, this being controlled by a guard on the instrument. After the bleeding has been controlled by means of pressure with cotton pledgets, the electrolyzer, consisting of two platinum blades in a handle, is passed through each of the incisions along their entire length. A current of 30 milliamperes is usually employed. It must be increased and decreased in strength very gradually. Currents of high frequency have also been employed with asserted success in this affection. The conjunctival surfaces are first cocainized, then with a flat nasal (Fig. 197) or similarly shaped vacuum electrode the application is made by rubbing it thoroughly, without removing it, over the affected surfaces for from five to ten minutes. Stephenson and Walsh[1] cured a long-standing case in four months by eight to fifteen minute applications over the non-everted lids, either sealing wax, glass, or a vulcanite electrode being used. A mild brush discharge may also be used. The glass vacuum electrode over the closed lids may be used with benefit in conjunctivitis accompanying dermatitis or eczema.

Fig. 282



Epilating forceps.

Electrolysis affords the best treatment for *trichiasis* when the displacement of the hairs is not due to general deformity of the lid. The operation is similar to that for superfluous hairs elsewhere (p. 366), *i. e.*, a delicate needle of iridoplatinum attached to a holder (Fig. 237) is connected with the negative pole of the battery; the anode is preferably held in the patient's hand. The needle is inserted along the hair into the follicle for a depth of about three millimeters, the hair being previously straightened out and held by means of epilation forceps (Fig. 282). The circuit is closed either by means of the interrupter on the handle (Fig. 237) or by the patient bringing the anode into contact with the palm of the hand when told to do so; the latter plan in this case is preferable, as, owing to the more or less twitching of the lid, all the efforts of the operator are required to keep the needle in place. A meter should be in the circuit and a current of one or two milliamperes used. When a white froth appears about the needle, which requires from ten to twenty seconds, the circuit is opened by the patient removing the electrode from the hand and the hair withdrawn by the forceps. It should come out without resistance; if any effort is required the operation

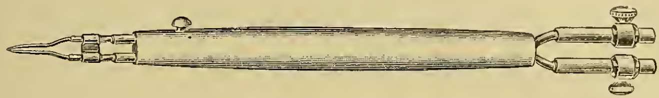
[1] Medical Press and Circular, February 18, 1903.

should be repeated. Some pain is caused, which, however, is not unbearable. The hairs may be magnified by wearing a lens.

Embedded powder grains in the conjunctiva and lids may be removed in a similar way to that described on page 331.

Small tumors of the lids and telangiectasis can be removed by electrolysis. The method is the same as employed for similar conditions elsewhere (pp. 362 and 371).

Fig. 283

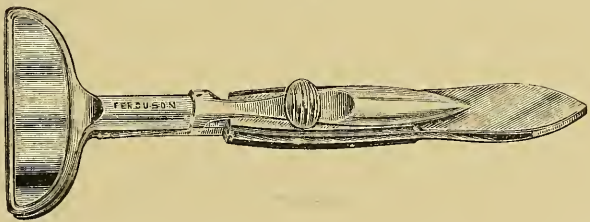


Galvanocautery handle and tip for galvanocautery puncture operation in ectropion and entropion. One-third reduction. (Ziegler.)

Chalazions have been removed by the insertion of a needle attached to the negative pole, the positive being held in the hand. It is asserted that the contents of the cyst will escape through the track of the needle and that the electrolytic action will cause obliteration of the sac.

Excessive thickening of the lids following either a chalazion or succession of styes may be treated by the galvanic current. Alleman recommends grasping the thickened portion with a pair of dressing forceps, which are attached by a cord to the negative pole, a current of 2 milliamperes being then passed for two or three minutes.

Fig. 284



Ziegler's lid clamp for use in galvanocautery puncture of the eyelids, either on conjunctival or skin surface.

Ziegler[1] uses, in the treatment of either *ectropion* or *entropion* due to various causes, the galvanocautery (p. 48). A row of deep punctures are made with a pointed cautery tip (Fig. 283), about 4 millimeters from the margin of the lid and separated from each other by an equal interval. The punctures should be made on the side we wish the contraction to take place, viz., the conjunctival side in ectropion, the skin side in entropion. If necessary, the operation can be repeated in from one to two weeks. During the operation, the lids should be held by a clamp (Fig. 284), as shown in Figs. 285 and 286. Afterward ice pads should be constantly applied for a few days until the swelling subsides.

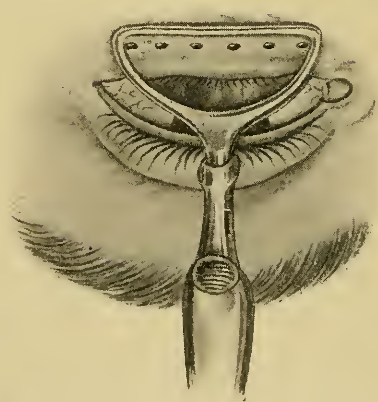
[1] Journal of the American Medical Association, July 17, 1909, p. 183.

Diseases of the Lacrymal Apparatus.—*Strictures of the canaliculus and duct* may be treated advantageously with electrolysis. The lacry-

FIG. 285

Lid clamp adjusted to case of ectropion, showing row of galvanocautery punctures on conjunctiva surface. (Ziegler.)

FIG. 286



Lid clamp adjusted to case of entropion, showing row of galvanocautery punctures on skin surfaces. (Ziegler.)

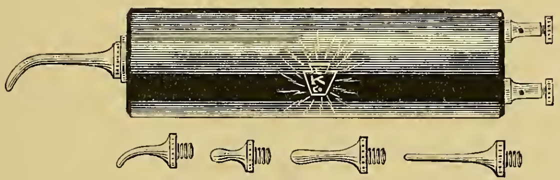
mal probe is passed in the ordinary way and then connected with the negative pole of the battery, the anode being held in the hand. A

current of from 2 to 4 milliamperes is passed for from two to five minutes. Some froth usually oozes out of the puncture, and in a very short time the stricture is so loosened that no resistance is felt when the probe is removed. The operation causes little or no increase of the pain produced by simple probing and hastens the removal of the obstruction. It should be performed once in six or ten days, the simple probe being passed once or twice in the interval. In recent cases of acute obstruction of the duct it has been claimed that the application over the canal of a vacuum electrode, a current of high frequency being used, will give good results.

Foreign Bodies.—The diagnosis and location of foreign bodies which have penetrated the eye may be greatly assisted by the x-rays (pp. 465 and 467). The electromagnet is of great service in removing *bits of steel* which have become embedded in the deeper parts of the eyeball.

Johnson has devised a magnet of such internal resistance that it can be attached directly to a 110-volt direct circuit. This instrument is portable, being $7\frac{1}{2}$ inches long from tip to tip, and is wound with two pounds and ten ounces of No. 27 single silk-covered wire. One

Fig. 287

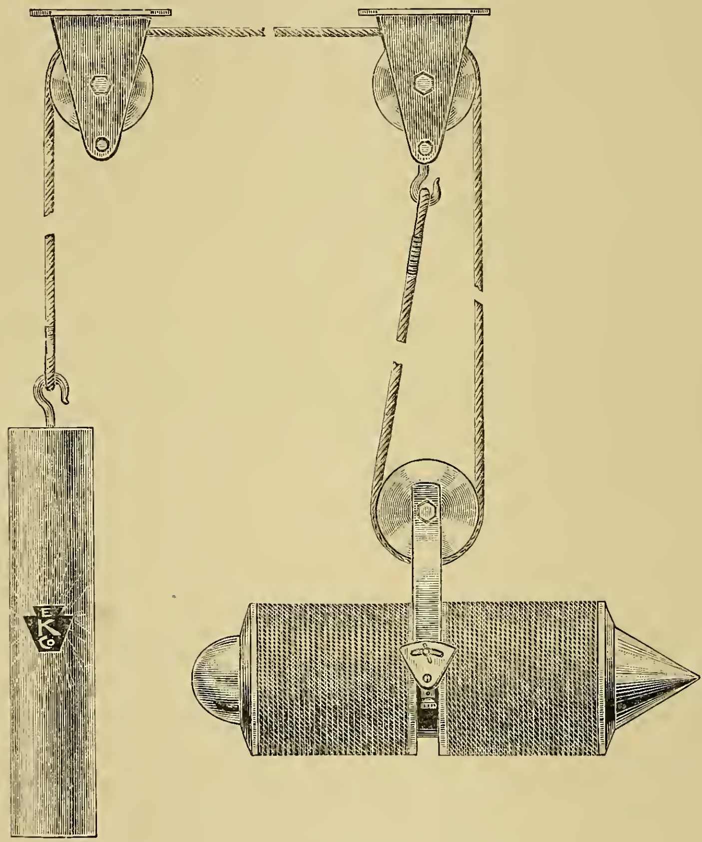


Hirschberg's eye magnet.

of the tips is $\frac{1}{2}$ inch long and ovoid in form, and the other is $1\frac{1}{2}$ inches long and elongated, and has a diameter of $\frac{3}{32}$ inch. The total weight of the instrument is three pounds and seven ounces. It can be easily carried and used wherever a direct current is obtainable The Hirschberg magnet (Fig. 287) is designed to be used with cells, from one to six being required to furnish the necessary current. In this instrument the soft iron core with the enveloping coil of wire constitute a handle into which may be screwed tips of various sizes and shapes. To secure the greatest amount of magnetic force a tip as short and thick as possible should be used. This is introduced into the eyeball either through the wound of entrance, which may be enlarged for the purpose, or, if the foreign body can be more conveniently reached in that way, an incision may be made through the sclera close to its situation. If possible, the tip should be brought into contact which the bit of steel that it is to remove, and in the withdrawal of the magnet it will come with it. If possible it is well to draw out with it the injured and infected tissue, which should be excised. It is important that the incision be large enough to prevent scraping off of the foreign body from the tip as it is withdrawn.

The Giant or Haab magnet (Fig. 288), is a stationary instrument of great power, designed to withdraw the steel without being brought into contact with it. When recent, the wound of entrance may be enlarged and the pole of the magnet brought near to it; the current is then turned on, when the fragment will come from the eye and adhere to it Another method is to draw the piece of steel to one side of the lens, against the iris, which it will cause to bulge; then, by changing the

Fig. 288



Haab's magnet.

direction of the eye, it may be drawn through the pupil into the anterior chamber, from which it can be extracted through a corneal incision either with a smaller magnet or forceps. All of these operations should be done aseptically.

Vascular Tumors and Angiomata of the Orbit.—Electrolysis, excepting in very large and rapidly increasing growths, which should be excised when possible, gives us probably the best method of treating these

tumors, as it possesses the advantage of safety and leaves no scar. Either of two methods may be used: First, one needle (the kathode) may be introduced, the other pole (a flat electrode) being placed either on the temple or some other indifferent point; second, the bipolar method, in which two needles are introduced, one connected with the kathode, the other with the anode. Unless the tumor is small, the latter method is preferable. Platinum needles with insulated shafts, as shown in Fig. 289, should be used. The strength of current used and the duration of

Fig. 289

Electric needle for vascular tumors of orbit: *A*, bayonet tip of platinum; *c*, *c*, insulation of shaft *B*.

the application are governed by the effects, *i. e.*, frothing about the kathode and pallor of the growth. When possible the needles are introduced at the junction of the tumor with the sound skin. If bleeding occurs after the withdrawal of the needles, compression should be employed. Bleeding may also be stopped by reintroducing the anode and turning on the current, as this pole coagulates blood (p. 113). The prognosis in these cases as regards the ultimate results should be guarded.

Paralysis of the Ocular Muscles.—Treatment of these conditions has been described on page 304.

Muscular Asthenopia.—In cases of *asthenopia* from *muscular weakness*, that is, "when the muscular equilibrium was not disturbed, but all the muscles lacked was the power of enduring prolonged work," and in cases of insufficiency of the interni, Alleman has obtained good results by using the galvanic current, 1 milliampere in strength, through the closed lids for five minutes, with frequent reversals of the current. He recommends similar treatment in cases "where, after correction of all the visual and muscular defects, there is still inability to use the eye as we could wish." In asthenopia with hyperesthesia of the retina, Rockwell recommends either mild labile faradic currents for five or ten minutes through the lids, the other electrode being on the nape of the neck or on the patient's hand or the galvanic current with the anode stabile on the closed eye. The headache resulting from eyestrain due to refractive errors can be relieved by the use of the brush discharge or static breeze.

CHAPTER XXIII

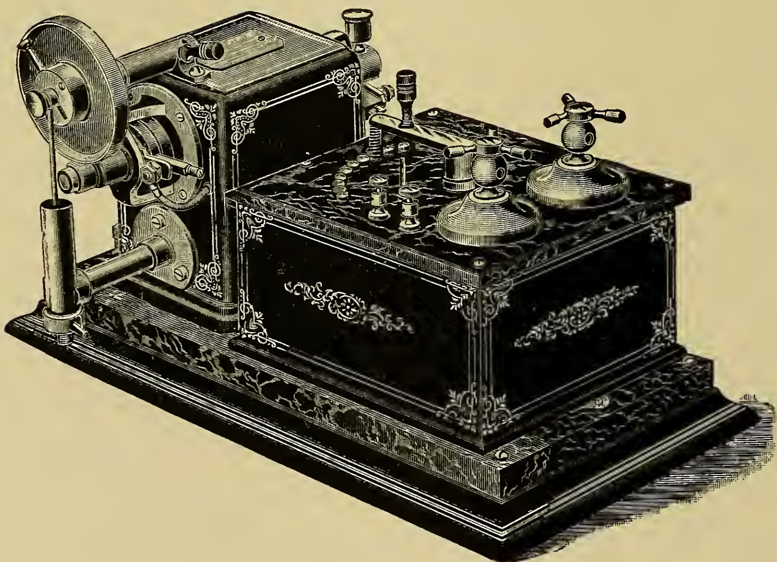
DISEASES OF THE THROAT, NOSE, AND EAR

SOURCE AND CONTROL OF CURRENT

Street Lighting Current.—This makes the most satisfactory source of electricity for the aurist and laryngologist.

Direct Street Current.—By interposing a suitable controller (Fig. 104) a galvanic or faradic current can be obtained, and the street current can be used for diagnostic lamps and to heat small stoves and sterilizers. A reducer or transformer (p. 85) must be added for cautery

Fig. 290



The Victor electrocautery with Pynchon's pneumomassage pump.

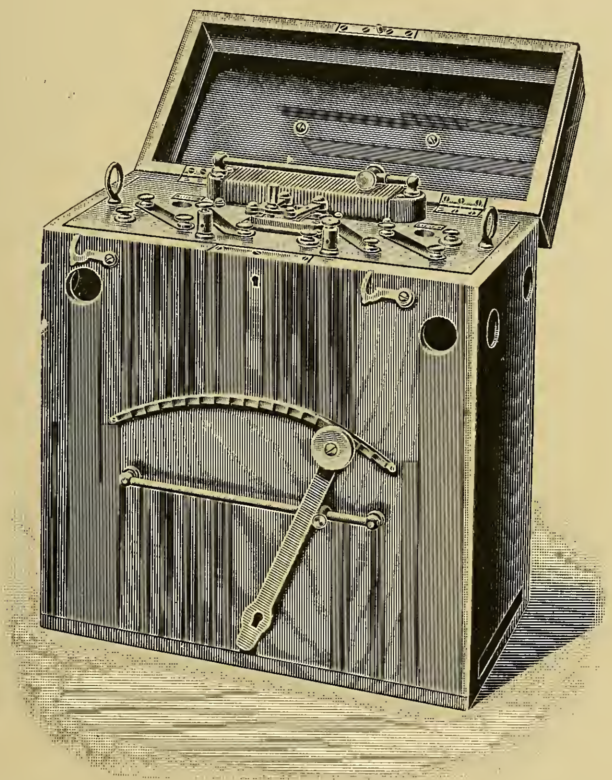
work (Fig. 61); the transformer may be so made that it can be used for nasal drill or saw, for vibratory massage, and for ear pump for ear massage (Fig. 290).

Alternating Street Current.—A reducer (p. 87) is necessary for cautery. A combination transformer is manufactured to supply cautery, a diagnostic lamp, nasal saw and drill, vibratory massage, and ear pump.

Storage Battery.—The storage battery or accumulator is also satisfactory (p. 59), and the various types of cells (pp. 54 to 59) may be employed.

When cells are used they must be arranged in parallel (p. 61). Therefore the battery used for ordinary therapeutic purposes, in which they are in series, will not answer. The preferable cell is the bichromate (p. 56). Such a battery is shown in Figs. 143, 291, and 292.

Fig. 291



Combination portable battery.

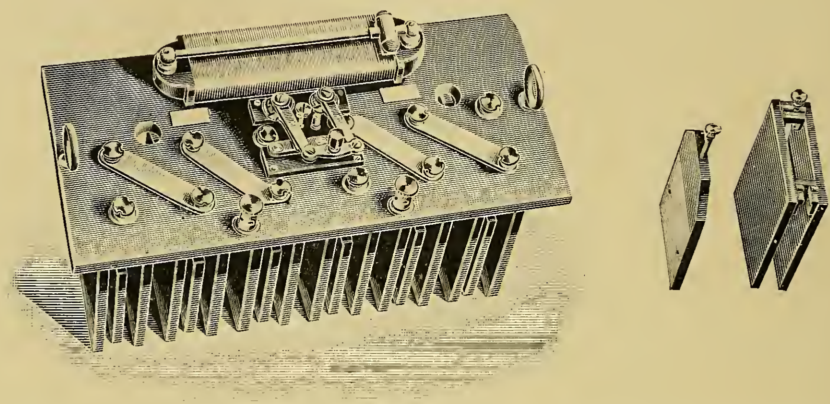
Control of Current.—To control the electric current, various controllers, transformers, and meters are employed, singly or mounted in cabinets or upon switchboards, which are described on pages 158 to 160.

Switchboards of many forms are on the market, equipped with controllers, transformers, and milliampere meters. The more elaborate can be connected with the 110-volt direct current to furnish galvanic and faradic current, power for surgical drill, ear massage pump, and for cautery and diagnostic lamp (Fig. 109).

The electric current has been adapted for the aurist and laryngologist

in so many ingenious ways that, in order to speak of them all, it is necessary to be as brief as possible, giving only practical details. As the subject has many branches, it will be discussed under four general heads:

Fig. 292



Portable and stationary bichromate plunge batteries for galvanocautery, endoscopy, and diaphanoscopy. Top plate and switchboard of battery with carbons, zincs, selector switch, rheostat, terminals and lifting rings.

(1) Source and control of current. (2) Use of electric current to furnish light, heat, and compressed air. (3) Use of electric current for diagnosis. (4) Use of electric current for treatment.

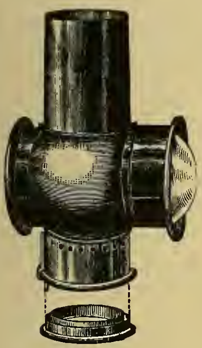
USE OF ELECTRIC CURRENT TO FURNISH LIGHT, HEAT, AND COMPRESSED AIR

Light.—A satisfactory light for examining the nose, throat, and ear is given by a frosted or ground-glass bulb in a Mackenzie condenser (Fig. 293). This is preferable to the ordinary electric bulb, which gives an unequal light and throws a shadow of its carbon filament upon the field under inspection.

Portable electric lamps are of convenience when treating patients confined to bed, and also affords a safe light for operations when ether is used. The current may be supplied by dry cells, or by wires connected with the ordinary house-light socket, current being reduced by some form of rheostat (Fig. 104). Lamps for the above purposes are usually made to be worn on the forehead, and are constructed in one of two ways. In the first, the light, focussed and magnified by a movable lens, is projected directly upon the patient, the disadvantages being that the lamp soon heats the forehead, and that the rays diverging make good illumination impossible when examining such localities as the drum membrane of the ear (Fig. 294).

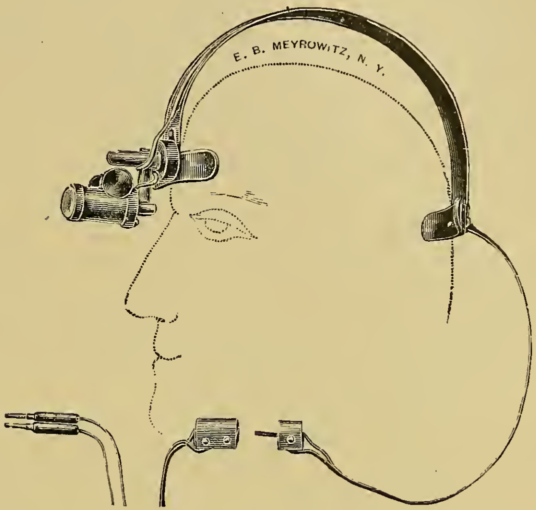
In the second form of lamp, a small electric bulb attached to the rim of the head mirror throws its light upon the mirror, from whence it is projected upon the part under inspection. The second kind of lamp

FIG. 293



Mackenzie condenser.

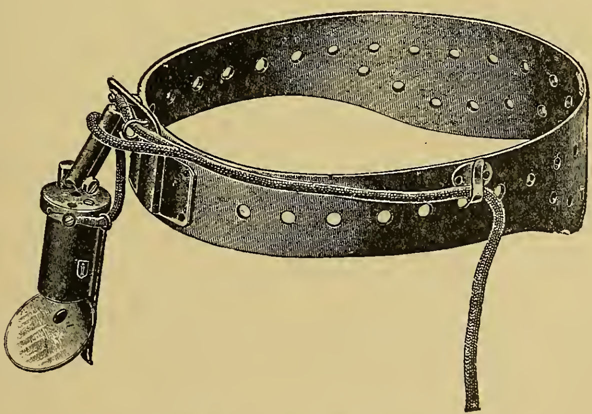
FIG. 294



Phillips' photophore.

does not become heated quickly, and gives better illumination because the rays of light are reflected in parallel lines; but, on the other hand, this form of lamp is apt to be more clumsy than the first (Fig. 295).

FIG. 295

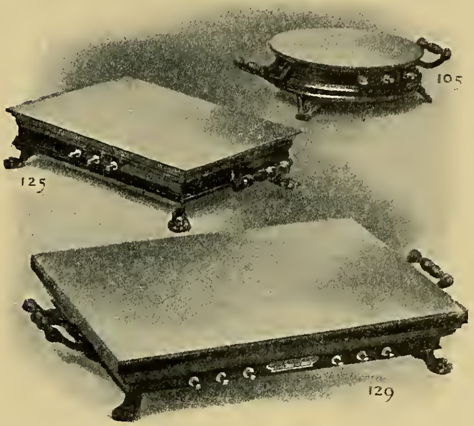


Kierstein lamp and head bracket.

Heat.—Electric stoves (Fig. 296) and sterilizers are of advantage when space has to be economized and current is not expensive. The

sterilizer illustrated (Fig. 297) has a fine-meshed metal basket which can be lifted out. The cords can be attached to the ordinary lamp socket.

Fig. 296

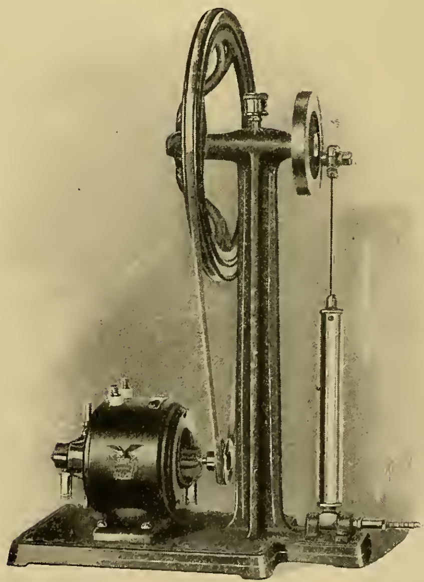


Electric stoves.

Fig. 297

Electric sterilizer.

Fig. 298



Automatic electric air compressor.

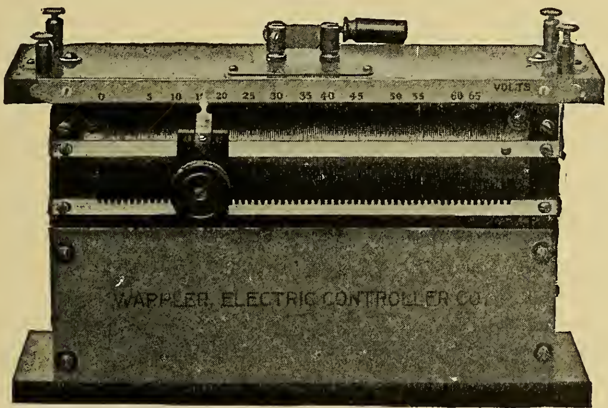
Atomizer bottle heaters keep solutions at body temperature. They also can be connected with the ordinary bulb socket.

Air compressors with automatic pressure controllers can be used to obtain compressed air for atomizers; when connected with the 110-volt direct street current, a pressure of 30 pounds can be obtained in a few minutes with the pump here illustrated (Fig. 298).

USE OF ELECTRIC CURRENT FOR DIAGNOSIS

Electricity, by producing light and the x-rays, is quite often of value to the specialist for purposes of diagnosis. Diagnostic lamps of many patterns are manufactured for directly illuminating the nose, throat, and ear, and for transilluminating the antrum and frontal sinuses, current for this purpose being obtained from portable dry-celled batteries, or from the street current, etc. (pp. 338 and 339). For direct illumination, small bulbs are employed, either alone or mounted upon a tongue depressor (Fig. 131), throat mirror, aural speculum, or polyp snare, these instruments being for the most part more ingenious than valuable (pp. 189 and 190).

Fig. 299



Coakley rheostat.

Transillumination.—For illuminating the sinuses, it is essential to have a rheostat to increase and lessen the intensity of the light, as by this means a better differentiation of the structures is obtainable (Fig. 299). Bulbs for transillumination should be of heavy glass in order to prevent them from heating rapidly, and should be capable of giving 5 to 8 candle-power (10-volt lamp of about one ampere current) (Fig. 300). The examination should be made in a dark room, or the heads of the physician and patient can be covered by a photographer's black cloth.

Antrum.—After removing any denture that may be present, the electric bulb is placed in the mouth and the lips tightly closed. The current is then switched on (Fig. 301).

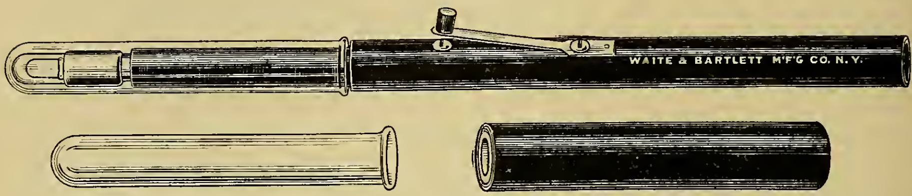
In normal conditions the rays of light pass upward and outward

unopposed through the hollow cavities of the face, producing the following results:

1. A diffused glow of light over the lower part of the cheek and between the separated jaws.

2. A semilunar patch of light immediately below the lower eyelid, caused by the passage of light rays through the anterior part of the orbital wall of the sinus.

Fig. 300



Coakley's transillumination apparatus with lamps and tubes.

3. A subjective sensation of light by the patient, as the current is switched on, sometimes more marked when the eyes are kept closed.

4. Illumination of the pupil by the rays penetrating the sclerotic, so that the centre of the eye is lighted up and glows like an animal's in the dark. In a healthy subject all of these may be present, but some are of more frequent occurrence and of greater value than others. Thus the

Fig. 301

Transillumination of the antrum. On the right side the cheek is lighted up, a semilunar band of light shows below the eye, and the pupil is illuminated. On the left the passage of light is obstructed. (St. Clair Thomson.)

third and fourth points are frequently wanting, and the second is the most valuable, and should be most carefully looked for.

When pus is present in the antrum of Highmore the passage of the rays is so obstructed that all these phenomena are diminished or abrogated. This transillumination test renders more service if only the

sinus on one side is suspected, when positive results are easily contrasted with the opposite side, and would lend strong confirmatory support. On the other hand a negative result would tend to indicate that the pus seen in the middle meatus came not from the maxillary, but from the frontal sinus. Transillumination may give positive results in the absence of an empyema, owing to:

1. Small size or complete absence of sinus.
2. Abnormal thickness of bony tissue.
3. Permanent thickening and opacity sometimes remaining in the lining of the cavity after complete cure of suppuration.
4. Presence of a malignant or other neoplasm.

Transillumination may give negative evidence, although the antral cavity is diseased, owing to:

1. The cavity happening to be more or less empty at the time of examination.
2. The bones being particularly thin and translucent.

The test must not, therefore, be too much relied on. If positive, it may arouse a suspicion or confirm other symptoms. If negative, it may point to other cavities as the source of pus, or may only indicate the necessity of seeking for other signs. The only positive evidence of a maxillary sinusitis is the expulsion of pus from the cavity.

The antrum can be transilluminated and the posterior nares illuminated by means of the Kyle lamp; the bulb is bent at an oblique angle with its shaft and is enclosed in a movable platinum cap; this cap acts as a reflector and has an aperture for the transmission of light. The lamp is inserted quickly back of the uvula, when the patient immediately closes his teeth upon the stem, holding the instrument firmly. The bulb can be retained for several minutes by turning off and on the current.

Frontal Sinus.—The same preparations are required as for applying the test to the maxillary sinus, but the electric globe is fitted with an opaque cap, which directs the rays in one longitudinal axis. This is pressed firmly against the lower wall of the sinus, under the inner third of the eyebrow. If there is nothing to interfere with the passage of the light rays, the clear frontal sinus will be lit up with its extensions upward and outward, and in some cases the septum and partial dissepiments will be defined. If one sinus only is obstructed these points become more evident by contrast (Fig. 302).

A form of transillumination lamp has been designed to illuminate both frontal sinuses at the same time.[1]

Objections to the Test.—Pus may be present in the sinus lying only on the floor, and the bone may be particularly translucent. Pus may be absent, and yet the test may fail to light up the cavities, owing to the great thinness of the sinuses, or even owing to their absence, or to the presence of a solid newgrowth, such as an osteoma.[2]

[1] Furet, Archives Internat. de Laryngol., March and April, 1899. p. 155.
[2] Posey and Wright, Diseases of the Eye, Ear, Nose, and Throat, p. 956.

Mastoid.—Transillumination of the mastoid process is of some value in determining the presence or absence of pus. The frontal transilluminating lamp is applied to the surface of the mastoid while the observer looks into the external auditory canal. The translucency of the bone should be compared with that of the other ear. The thickness of the bone and similar factors must be taken into account in drawing conclusions.[1]

Fig. 302

Transillumination of the frontal sinus. Right sinus illuminated, while left remains obscure. (St. Clair Thompson.)

Larynx.—Freudenthal has devised a lamp for transillumination of the larynx. A yellowish-red light is thrown from outside through the laryngeal tissues, making their appearance in the laryngoscopic mirror quite different from the ordinary. This method has not come into general use. The use of electricity as a diagnostic aid in diseases of the labyrinth and auditory nerve is described on page 177.

X-rays.—The *x*-rays occasionally are of service in locating foreign bodies, but their application for this purpose about the ear, nose, and throat does not differ from their application elsewhere (p. 466). Quite recently it has been found possible to obtain skiagraphs of the frontal and maxillary sinuses. These pictures show not only the size and shape of the sinuses, but also may indicate pathological changes, giving valuable information for purposes of diagnosis and in guiding the surgeon in his choice of operation.

USE OF ELECTRIC CURRENT FOR TREATMENT

Electricity is more and more coming into use in the treatment of diseases of the nose, throat, and ear. The most valuable ways of apply-

[1] See Anderson's article on Physical Examination of the Mastoid, in the Transactions of the Academy of Ophthalmology and Otolaryngology, 1905.

ing it are by use of the cautery for the control of hemorrhage and removal of growths, the faradic and galvanic currents for paralysis, and the x-rays for malignant disease and tuberculosis (pp. 474 and 476). For the sake of completeness these and many other ways of using electricity for treatment will be taken up seriatum. The uses of the electric light as a therapeutic measure are discussed on pages 288 and 289.

Fig. 303

Schech's cautery handle.

Cautery.—A simple form of cautery outfit consists of four or more good dry cells connected in parallel (p. 61) by ordinary insulated bell wire to a handle into which is inserted a cautery blade. The handle must have a stop button. Such an apparatus costs about six dollars and answers for occasional use in minor rhinologic work, but the street current will be found the most satisfactory source of current when much cautery work is to be done, although any other source can be used (p. 338). The cautery requires from 6 to 10 volts, and usually a rheostat must be interposed. The best handle is Schech's (Fig. 303). Another less expensive one is sold that answers fairly well (Fig. 304). Both of

Fig. 304

Cautery handle and electrode.

these can be used with cautery knife and snare. Cautery knives are made in various forms (Fig. 305), and snare wire is made of platinum and iridium, platinum by itself being scarcely rigid enough. It might be suggested that, as far as possible, pointed and narrow edged knives should be used, as they produce much less pain and reaction than broad, flat ones. An equipment should contain a slender, straight-pointed

electrode, a second bent at right angles three-quarters of an inch from the end, and a third long, heavier knife, with a curved shaft to reach the base of the tongue and into the larynx.

The wire of the snare is threaded through a cannula and attached to a ring, by which it is operated.

Fig. 305

Cautery points.

Technique.—A 5 per cent. solution of cocaine is applied with cotton-tipped applicator to the part to be cauterized. After an interval of five minutes the surface is dried, and is then ready for the cautery. The electrode is applied cold and the current turned on, the burning being done with the knife or wire at a bright cherry-red heat (not at a white heat, which would cause too much destruction and be followed by hemorrhage). The blade is moved until the desired amount has been cauterized, and is taken away just as the current is turned off. When it is turned off too soon, the knife, cooling, will adhere and tear the tissues; if it is felt to adhere in this way, the current should be turned on again. The cautery knife and snare wire require more current when embedded in tissue than when outside.

Diseases and Technique.—The cautery blade is used in epistaxis to destroy small eroded vessels; it is used also to reduce small nasal growths and hypertrophies, such as those found at the tubercle and posterior edge of the septum, and to destroy papillomata and angiomata. When employed for the purpose of lessening hypertrophies of the lower turbinates two ways are recommended. The first consists of one or two deep cauterizations made from behind forward, pinning the mucosa to the bone; the second is started by making a small incision into the mucosa, through which the electrode is passed into the spongy erectile tissue of the turbinate; the current is then turned on and the knife moved about and withdrawn. The advantage of the second or submucous method is absence of after-treatment and scar. Only one nostril should be treated at a sitting, and sittings should not come at less intervals than five days. Adhesions sometimes take place between the cauterized turbinates and the septum, although this usually can be avoided by not touching the septum with the electrode. If this complication occurs, the adhesion should be let alone until inflammation has sub-

sided and the turbinate has retracted, when it can be severed and kept open with lint or rubber tissue. A sore throat and even acute tonsillitis occasionally follows the use of the cautery in the nose. Sensitive areas in the nose causing reflex symptoms elsewhere are satisfactorily treated with the cautery, and malignant growths of the nose and nasopharynx, *e. g.*, fibroid, can sometimes be removed with cautery blade or snare. Polyps and hypertrophies of the middle turbinate should never be removed by the electric cautery, on account of the danger of producing phlebitis in veins leading to the longitudinal sinus, and possibly septic meningitis. The use of the electric cautery or snare for the removal of posterior hypertrophies of the turbinate is attended with risk of causing otitis media; to avoid this, the distance of the tube mouth from the entrance of the nose can be marked on the cautery knife, the measurement being made with a Eustachian catheter by engaging the turn of the instrument on the posterior edge of the septum, the distance to that point from the nasal entrance being the exact length to the tube mouth. The after effects of the milder operation are seldom more than a coryza with occlusion of the operated nostril with swelling. This lasts for a few days, and is followed by a watery or mucopurulent discharge, which in a week becomes scanty with a tendency to crust. A fibrinous exudate occurs along the line of the cautery wound, persisting with the second week. In the process of cleansing the nose in after-treatment, this should not be disturbed, for if destroyed a general acute rhinitis will follow. Some simple ointment can be applied to the wound immediately after the operation.

The cautery knife is of value for removing enlarged follicles on the pharyngeal and hypertrophied lateral folds, the blade being placed at right angles to the lateral fold. Very little must be done at a time, as the reaction is likely to be great. The short curved knife is sometimes of convenience in opening up crypts of the tonsil and in treating large, flat tonsils that do not protrude between the faucial pillars; in these cases care must be exercised to avoid burning the pillars. The technique is as follows: After cocainizing the tonsil, either by applying a 4 per cent. solution to the surface or by injecting a few drops of a 2 per cent. solution with a hemorrhoid hypodermic needle, the galvanocautery point is introduced deep into the crypts, cutting through the intervening tissue. Only a small portion of one tonsil should be treated at a time, and three or four sittings may be required at intervals of a week before the tonsil is removed.

It is a question whether there is any advantage in removing enlarged faucial tonsils with the cautery snare unless the tonsils are very fibrous, and in cases of hemophilia. If the hot snare is decided upon, Knight's tonsil snare (Fig. 306) can be readily attached to Schech's cautery handle (Fig. 303). It has a ring to which the wire loop is fastened by a piece of thread; this arrangement facilitates its adjustment over the tonsil. Any adhesions between the pillars and the tonsil having been broken and the loop applied, the current is turned on until a bright

cherry-red color is obtained, and traction is then made on the wire. About four minutes will elapse before the loop will burn its way through the tonsil. If the wire is at white heat there will be danger of hemorrhage.

Hypertrophied lingual tonsils can be removed with electric blade or snare; the same cautions given in connection with the faucial tonsils apply here as well. Lingual varices at the base of the tongue can be successfully destroyed with a curved electrode applied transversely to the veins; two or three only should be treated at a sitting. The electric cautery makes also one of the best instruments at our command for the cure of mycosis of the fauces. Applications must be made deep into the tissue.

The larynx is not very safe ground for the cautery, unless used by one thoroughly experienced. In cauterizing tuberculous swellings, however, there is not as much reaction as one would expect, and the electrode can be used to reduce papillomatous and edematous tuberculomata, as well as for cauterizing after the curette has been used. The larger knives are sometimes used in extralaryngeal operations, to remove tumors and to cauterize their bases after cutting has been done.

Fig. 306

Knight's tonsil galvanocautery snare.

Some specialists cauterize granulations and the stumps of polyps in the ear, and even make openings through the drum membrane, with the electric cautery, but I believe such procedures can be undertaken with much safer instruments. The cautery blade may, however, be used for opening the lateral sinus in sinus thrombosis, as it sterilizes the sinus wall when it passes through.

Electric Burrs and Trephines.—Burrs and trephines attached to a flexible dental hand shaft and operated by an electric motor (Fig. 44) are employed by some physicians for removing certain forms of nasal obstructions, for entering the antrum and frontal sinus, for opening bone in the mastoid operations, and making osteoplastic flaps. The hand shaft must be thoroughly under control, for serious harm might result if the instrument should slip.

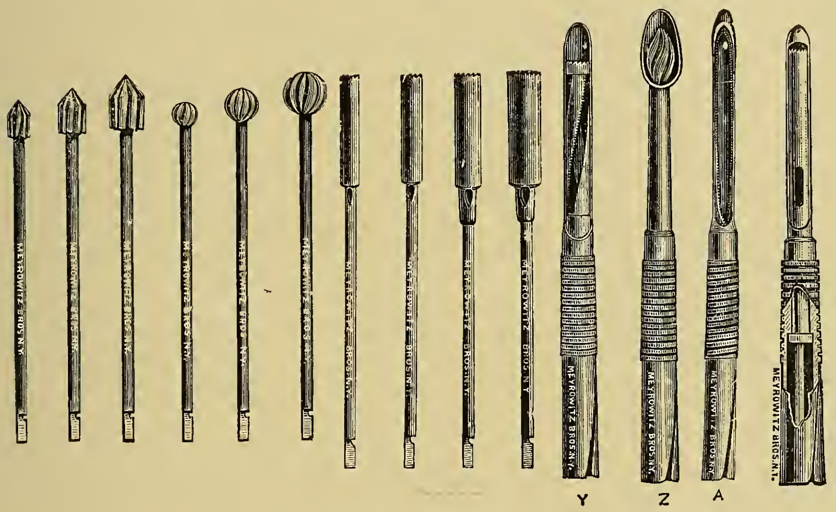
Nasal Obstructions.—The trephine (Fig. 307) can be used to remove septal ridges and enlarged lower turbinates, cocaine and adrenalin being first applied as in other operations upon the nose; the portions of tissue removed are in the form of cylindrical cores. After removal of septal growths the edges made by the trephine must be trimmed by scissors or some similar instrument, and although it is true that the operation is more quickly and easily performed with the trephine than with a saw, it

is also true that the shock to the patient is greater and the surface of the wound is not left as smooth. In operations upon the lower turbinates the core is taken out in the long axis of the bone without breaking the mucosa except at the point of entrance, at which place a preliminary incision is made before introducing the trephine.

When septal spurs are to be removed with a mechanical saw, the electric motor must be capable of making at least 3000 revolutions per minute.

Frontal and Maxillary Sinuses.—A special trephine has been devised for entering the frontal sinus through the nose, being guided by a previously introduced probe. Such an operation is not likely to become popular because of the danger of opening the cranial cavity. On the other hand, a trephine makes a very satisfactory instrument for opening

Fig. 307



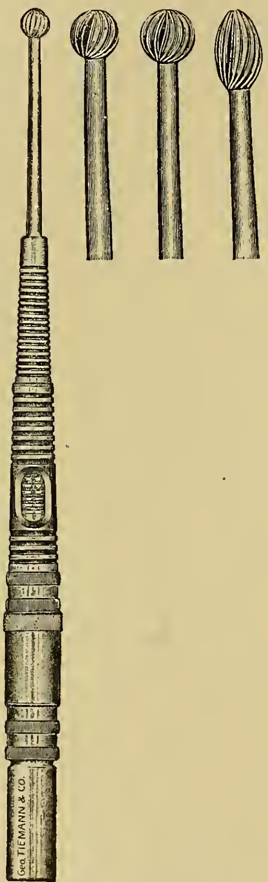
Nasal burrs and trephines.

the antrum through the lower meatus after removal of the anterior portion of the lower turbinate. This operation requires general anesthesia, and the opening should be cut large enough to permit thorough curettement and packing of the sinus. The antrum may also be drained by an opening made with a small burr through the alveolar process, provided a bicuspid tooth on the diseased side is lacking or is carious enough to require removal; the burr should be made to follow exactly the course of the tooth socket. In the mastoid operation the bone may be entered by means of the Macewen burr (Fig. 308); it is of globular form, with a hard and sharp spiral cutting edge.

Vibratory Massage.—This has received much attention of late, and probably has some value in the treatment of subacute and chronic inflammation of the nose, throat, Eustachian tube, and middle ear.

In cases of chronic hypertrophic and atrophic rhinitis massage is given by means of a cotton-tipped probe attached to a handle made for the purpose (Fig. 309), and operated by an electric motor (p. 294); the number of vibrations can be regulated up to 8000 per minute, and treatment is given two or three times a week. In throat and ear affections, curved or straight tips of rubber (Fig. 311), connected with a small handle, are

Fig. 308



Macewen's burrs.

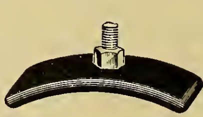
Fig. 309

Straight probe for mucous membranes.

Fig. 310

Soft rubber cone, for facial application, especially around nose and eyes.

Fig. 311



Curved applicator for throat and curved surfaces.

applied over the parotid and mastoid, and along the anterior border of the sternomastoid muscle down to the clavicle; sittings of five minutes are given daily. For massage of the orifices of the Eustachian tubes a curved probe introduced through the mouth has been used.[1] Vibratory massage treatment should never be violent, and should be stopped at the first signs of fatigue.

[1] Bruhl's Otology, p. 133.

Massage of the drum membrane of the ear, by means of the Siegle otoscope connected with an air pump operated by the electric motor (Fig. 292), has been recommended by some writers, and very ingenious instruments have been devised for controlling the length of stroke and speed of the pump. It is a question whether such mechanical contrivances are as effective as the hand bulb operated by the hand of the physician. However applied, massage of the drum membrane and middle ear is often followed by permanent improvement when adhesive processes are going on, such as are due to chronic catarrhal and previous purulent otitis media; only temporary improvement may be expected when adhesions have formed and when there is immobility of the ossicles with labyrinthine involvement. The pump must be able to give four hundred vibrations a minute; the length of stroke should not exceed two millimeters. Sittings of five to ten minutes may be given daily or at longer intervals, but continuous treatment of this kind must not be given for longer than five weeks at a time. It is said that slow vibrations (30 to 90) are best adapted to middle-ear conditions, and that more rapid vibrations (300 and over) have more pronounced effect when the labyrinth is affected. The drum membrane should be under inspection during the treatment until the tolerance of the patient is learned.

Old cases with tough, thickened tympanic membranes will stand greater dosage, although tolerance will increase in most cases as treatment progresses. A faint reddening of the drum membrane is an indication to discontinue the massage, as also are pain, vertigo, and increase of tinnitus; other contraindications are acute inflammation, or atrophy, of the drum membrane.[1]

Dry Heat.—An apparatus heated by electricity is manufactured for the purpose of throwing heated air into the external auditory canal (Figs. 312 and 313). This method of treating chronic catarrhal otitis media has not found much favor with the profession, although a few claim good results in unfavorable cases. Dry heat used in the nose has also been recommended in the treatment of headache due to sinus disease, and for tinnitus and deafness caused by chronic otitis media. For this purpose the physician can use the electric hot air syringe made for dentists, with which hot air can be delivered to the sinus openings directly and through a Eustachian catheter to the ear. The air must be applied in puffs, with intermissions, in order not to burn the patient. If a metal catheter with non-conducting cover is used, the operator will desist when the patient flinches. Rubber catheters will not burn the tube mouth, for they straighten out when the heat becomes too great. Treatment is continued over five minutes, and repeated in a few days if necessary; it is claimed that often a single treatment will permanently relieve tinnitus, and also headache due to sinus congestion.[2]

[1] It is the writer's practice to use the hand bulb attached to a Siegle otoscope for massaging the drum membrane; this is given for about thirty seconds after the middle ear has been inflated.

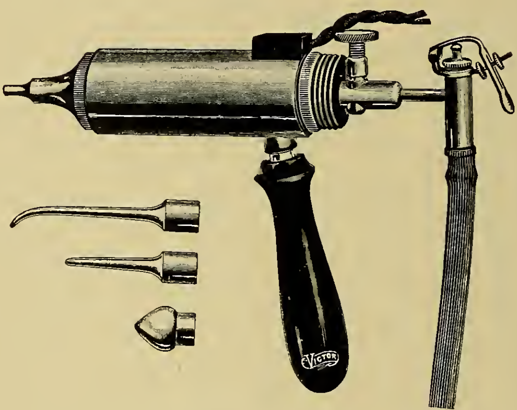
[2] Presse Médicale, Paris, 1905, No. 2.

X-rays.—The x-rays are used, but often without much success, in the treatment of *malignant disease* of ear, nose, and throat; in some cases it relieves pain. It may be tried in inoperable cases, and in other cases after operation. More satisfactory results are obtained with the x-rays in laryngeal tuberculosis, for not only is dysphagia often relieved, but after the stage of irritation is passed, in some instances a lessening of congestion takes place with healing of the lesion. A case of tuberculosis of lung and larynx, in which the disease was arrested by the use of x-rays, was reported by the writer in the *American Journal of the Medical Sciences*, June, 1905. A high tension tube was used, at a distance of ten inches, five-minute exposure of lung and neck every other day for eight weeks.

FIG. 312

Compressed air heater. Supplies from 300° to 500° F.

FIG. 313



Victor electric air heater.

Galvanic and Faradic Electricity.—This is of great value in the treatment of curable peripheral neuroses of the nose, throat, and ear, and does good by stimulating the nerves and preventing atrophy of disused muscles, also by mental impression in some cases. The current should never be strong enough to occasion pain, and when used in cases of recent paralysis, should not be applied until the stage of irritation is past, *e. g.*, in injury of the facial nerve during mastoid operation electricity should not be used until after the third week. When the throat is involved it is largely a matter of taste whether the current should be used externally or internally. Applications extending over one to three minutes can be made daily or every other day. If the galvanic current is applied externally, a current of 10 to 15 milliamperes will be sufficient; internally, 5 milliamperes. There will be less chance of burning the mucosa if the electrode is broad.

The following list includes most of the diseases in which faradic and galvanic electricity is indicated: Facial, post-diphtheritic, and bulbar

paralysis; nasal hydrorrhea; atrophic rhinitis; paresthesias of pharynx; anesthesia and paralysis of the muscles of the larynx; laryngismus stridulus; spasmodic laryngeal cough; hysterical aphonia; otalgia following middle-ear inflammation; and tinnitus. In the treatment of tinnitus the positive electrode (anode) is usually applied to the tragus, and the negative (kathode) either to the back of the neck or over the sternum. Ordinarily tinnitus diminishes during anodal closure and increases during kathodal closure, in which case the anode should be closed and current allowed to flow five to twenty minutes; afterward the current strength is reduced slowly, so that no opening reaction takes place. In some cases tinnitus will be lessened during kathodal closure, in which event the current should be given chiefly during kathodal closure.[1]

Electrolysis.—This method of treatment has certain disadvantages that prevent it from being used as much as might be expected on theoretical grounds, the chief disadvantage being its slowness of action. We shall consider the method in a general way, and then give in detail the technique of its use in various diseases of the ear and throat. The principles are explained on pages 49 and 113.

In the employment of this agency in diseases of the throat and nose, the strength of current depends on the condition being treated. Weak currents (2 to 10 milliamperes) are employed for milder pathological conditions; for some of the more serious diseases, such as fibroid of the nasopharynx and other malignant growths, 10 to 30 milliamperes and even such strengths as 50 milliamperes and more have been used, being equivalent to the most serious major operations in their effect upon the organism. They require a general anesthetic, and may be attended by fatal shock (p. 392).

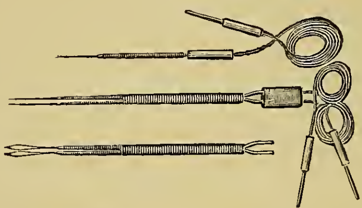
For simple electrolysis the positive electrode should be made of gold, silver, or iridioplatinum; if the negative pole is being employed, steel may be used. When it is desired to carry metallic and medicinal substances into deeper inaccessible tissues, the property of phoresis (p. 114) may be utilized. The medicine in solution should be applied to the surface and the electrode placed over it; or if it is desired to obtain the action of certain metallic salts, the positive electrode can be made of the desired metal. When the current is passed through the tissues particles of the medicine or metallic salts, will be carried from the positive toward the negative pole (cataphoresis). The metallic electrodes employed for this purpose are made of copper or of zinc; from the copper are formed cupric oxides and chlorides; from the zinc the oxychlorides of zinc. These electrodes may be dipped into metallic mercury, forming in this way an amalgam, and when applied with the electric current, mercury globules penetrate into the tissues, the direction always being, as said above, from the positive toward the negative pole (p. 392).

[1] See also article by Lewis Jones, Archives of Otology, vol. xxiv.

General Uses of Electrolysis; Advantages and Disadvantages.—Electrolysis is used to produce an alterative effect upon pathological conditions of the mucosa, to reduce redundant tissue and fibrous strictures, and to destroy tumors and malignant growths. It produces little or no inflammatory reaction and no bleeding. It is claimed for phoresis that medicinal salts are carried by diffusion into inaccessible parts and that these nascent salts are more active than in their normal chemical condition. The disadvantages to electrolysis are that it is slow and not free from pain; that it requires considerable apparatus and some experience, and that malignant disease beyond the reach of the knife and cautery is also beyond its reach.

Apparatus.—As elsewhere, the galvanic current must be used. The apparatus and general rules of application being the same as when employed in other localities (pp. 267 and 271). It is necessary to have a reliable rheostat and milliamperemeter to control and measure the current. Needles for use in throat and nose work are shown in Fig. 314

Fig. 314



Delavan's electrolysis needles, unipolar and bipolar. (Kyle.)

General Technique.—No anesthetic is required for currents below 3 milliamperes; between 3 and 10 milliamperes cocaine, 4 per cent., should be applied, and for strengths over 10 milliamperes a general anesthetic is necessary. The current should start at nothing, be slowly increased, and then slowly diminished; the length of application varies from two to twenty minutes, and for the lower strengths the endurance of the patient will indicate how much may be used. When destroying tissues, a white foam appears as the current passes, but the size of the part destroyed will not be evident until the second or third day, at which time the slough forms. The eschar comes away about the eighth or tenth day. After-treatment consists of the use of boric wash or powder. For further rules to be observed in the employment of electrolyses, see p. 267.

Diseases in Which Electrolysis is Used.—Nose.—*Chronic Rhinitis and Intumescent Rhinitis.*—Simple electrolysis, positive monapolar, 1 to 3 milliamperes, or bipolar, 5 milliamperes, two to ten minutes.

Hypertrophic Rhinitis.—Simple or cataphoric electrolysis; for the latter a copper needle attached to the positive pole is inserted into a turbinate, and a steel or platinum needle attached to the negative pole into the septum.

Excoriations of Septum.—Cupric electrolysis.

Septal Spurs and Ridges.—Simple bipolar electrolysis after cocainization, 15 milliamperes are generally sufficient; seance should not exceed fifteen minutes. Mass should be detached in a plane parallel to the normal plane of the septum.

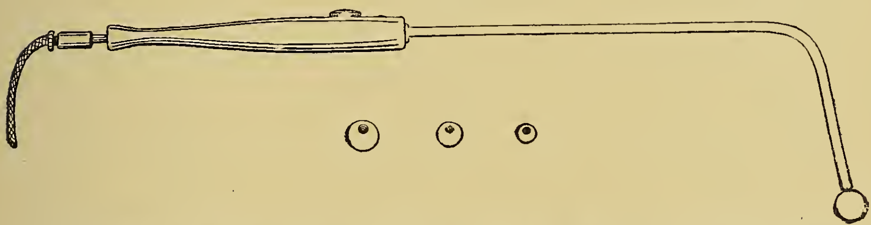
Angioma of Septum.—Simple bipolar electrolysis or alternately positive and negative.

Malignant Disease.—Cataphoresis, zinc positive electrode, 10 to 30 milliamperes, under local or general anesthesia (p. 392).[1]

Fibroid Tumor.—Simple negative electrolysis, 5 to 10 milliamperes, three to twenty minutes. McBride refers to the value of the electrolytic snare and forceps in these cases.[2] Ordinary piano wire insulated by being dipped into rubber and chloroform is threaded in the snare and attached to the negative pole, and a large moist sponge electrode is applied to the cheek.

LARYNX.—Grunwald advises the use of electrolysis in pachydermic laryngitis and for melting the bases of ulcers. For tuberculosis of the larynx he employs dipolar electrolysis, 15 to 20 milliamperes, although such strengths are more drastic than the cautery. Cupric electrolysis (Fig. 315) under cocaine anesthesia is also used, 1 to 3 milliamperes for five minutes.

FIG. 315



Scheppegrell's laryngeal electrode and handle for cupric electrolysis, with extraspherical points. (Kyle.)

EAR.—The use of electrolysis for the reduction of obstructive swellings of the Eustachian tube has given rise to considerable discussion during the last ten years. It seems to possess little if any advantage over simple dilatation with the Eustachian bougie. The technique is as follows:

The catheter is insulated by winding a thin strip of rubber tissue around it. An olive-tipped gold bougie is then passed through the catheter after the latter has been placed in the Eustachian opening. The bougie is passed on until an obstruction is encountered. It should be said here that the bougie is connected with the negative pole of the battery, while the positive large sponge electrode is held in the patient's hand. The galvanic current is slowly turned on as soon as the bougie is halted in its progress, until the milliamperemeter registers 3 to 5 milliamperes

[1] See also New Orleans Medical and Surgical Journal, December, 1903, and Paper by Massey, Trans. Philadelphia County Medical Society, 1902.

[2] Diseases of Throat, Nose, and Ear, p. 295.

of current. Slow pressure is maintained upon the bougie, and after a short interval, the instrument will glide by the obstruction.

High Frequency Currents.—The antiseptic and stimulating properties (p. 139) of this modality have been shown to be of use in the treatment of certain diseases of the nose and throat. The current from either the secondary Tesla coil or Oudin resonator is employed, being administered with a vacuum electrode, as shown in Figs. 197 and 201. The current must not be too strong, usually about 1 ampere if a meter is at hand; otherwise, when a feeling of warmth is experienced the strength is sufficient. The application should last from five to ten minutes, and the position of the electrode must be watched carefully by means of the head mirror. It is well not to allow the electrode to touch the bony septum, as it is quite sensitive. The mucous membrane should first be cleansed by means of an antiseptic, alkaline spray, and if very sensitive, cocaine may be applied.

Acute rhinitis may be relieved in from one to three treatments. Good results are obtained in *chronic rhinitis*. In this the power of the high frequency current to cause the penetration of drugs (p. 277) may be utilized and iodine painted on the affected parts before the electrode is introduced. The swelling of *hypertrophied turbinates* may be readily reduced by the employment of this current. Soule[1] advises it in *atrophic rhinitis* or *ozena*. After removing the crusts, he anesthetizes the parts and applies short sparks to the membrane until it becomes a rosy red. After this, with a weaker current, he rubs the electrode over the membrane. After the application the nose should be dressed with bland oil by means of a spray, and if bad, pack the nares with lamb's wool. The treatment must be repeated daily. The same author claims to have aborted *acute tonsillitis* by the use of sparks applied to the tonsils; the method, however, requires considerable technical skill, and as such cases are usually bedfast, the current is not often convenient. *Acute laryngitis* may be relieved by placing the electrode over the larynx. In *tubercular laryngitis* applications to the larynx give good results.

[1] Journal of Advanced Therapeutics, June, 1909, p. 298.

CHAPTER XXIV

DISEASES OF THE SKIN

All forms and properties of the electric current have been utilized in the treatment of diseases of the skin, *i. e.*, the galvanocautery, electrolysis, high frequency and static sparks, and the *x*-rays for the destruction of diseased tissue and abnormal growths; the static and high frequency currents for their influence upon metabolism, and also in the case of the latter for its local action upon diseased tissue; the faradic and galvanic currents for their respective stimulating and sedative properties; and phoresis for the introducing of remedies into the skin. In treating diseases of the skin it is essential that in the galvanic circuit there is a rheostat or current controller which will enable

Fig. 316

Fig. 317

Fig. 318

Cautery electrodes.

the current to be either increased or decreased gradually (Fig. 105), and a milliamperemeter (Fig. 46). In addition to the ordinary electrodes, fine needles made of either platinum, iridoplatinum, or gold, with a suitable holder (steel needles become corroded and stain the skin) (Fig. 238), an electrode for cataphoresis (Fig. 241), and cautery electrodes to meet the indications of ignipuncture, excision, or superficial searing are essential. A few types of these are shown in Figs. 316, 317, 318, and also 305.

The technique and therapeutic indications for the employment of the *x*-rays are dicussed in Section VII (pp. 472 and 475).

The question may, however, arise in certain cases as to which is preferable, high frequency currents with a vacuum tube or *x*-rays. In general it may be said that cases where the lesion is one of overactivity with undue proliferation of cellular tissue, especially when glandular, should be exposed to the *x*-rays; when, however, a counter-

irritant and absorbent effect is desired, the former is usually preferable (pp. 139 and 140).

Acne.—When the lesions are inclined to be sluggish, without any tendency to resolution, the application of the galvanic current is of decided benefit. Before applying the current the cheesy contents of comedones should be expressed by means of either a watch key or comedo extractor, and the contents of pustules evacuated; after this the affected area must be washed with an antiseptic solution. The anode, consisting of an electrode about six inches square covered with cotton, is placed over the lesions, and the kathode at an indifferent point. The strength of the current should be gradually increased until it causes a sensation of warmth, usually 5 to 10 milliamperes being required and the current should be allowed to pass for five minutes at each point to which the electrode is applied and then gradually decreased. If there are breaks in the continuity of the skin the application is painful, therefore a weaker current and a shorter period of application should be employed. This method lessens the congestion and removes the infiltration from the surrounding tissues. A more stimulating effect can be produced by reversing the poles.

After the galvanic current has been employed in the manner just described, the sebaceous glands should be next touched with an irido-platinum needle, previously sterilized by heat. The needle is made the anode and is introduced into the gland, a current of 3 to 5 milliamperes being thus applied for about thirty seconds. This will improve the functional activity of the gland. Hayes recommends making the needle the kathode, and says that by so doing a slight amount of electrolysis will so dilate the entrance of the gland that the contents can be readily expressed, while at the same time the inflammatory reaction produced will be sufficient to obliterate it. In comedones with large patulous openings a needle introduced into the follicle two or three times, at intervals of five or six days, a current of about 3 milliamperes being employed, will be beneficial. When double comedones exist a similar method, using a stronger current, will destroy the canal connecting the two glands. The static current, applying mild sparks to the diseased surface, will stimulate the action of the skin; the high frequency (Tesla) current with vacuum electrode can also be employed for this purpose. Galvanism can be used as recommended for the other lesions of acne. Central galvanization, general faradization, and the high frequency currents by the methods of autoconduction, autocondensation, or wave current may be used for their tonic and eliminative effects.

Acne Rosacea.—Electricity is of great value in this affection, especially in those cases in which there is enlargement of the capillary bloodvessels. In the first or hyperemic stage either the treatment detailed for acne may be employed, or, what is better, labile anodal galvanization, the electrode being moved in the direction of the venous current, *i. e.*, toward the heart, can be used. When there are dilated capillaries in addition to this method, the enlarged vessels should be destroyed by

electrolysis. For this purpose a previously sterilized iridoplatinum needle attached to the negative pole, the positive being at an indifferent point (the patient's hand), is introduced so that it either traverses a portion of the dilated vessel or else transfixes it. After the introduction of the needle the circuit is closed either by the patient grasping the positive electrode or by means of an interrupter in the handle of the needle holder (Fig. 237). The strength of the current should be from one to three milliamperes, or that derived from four to ten cells. The application should be continued until the vessel walls are thoroughly destroyed, so that no flow of blood follows the withdrawal of the needle. If the vessel is simply transfixed, it should be done in several places along its course. As a marked reaction generally ensues, and the parts affected, the nose and face, are sensitive, not more than five or six punctures should be made at each sitting. Sufficient time should elapse after each sitting for this reaction to subside. Williams[1] recommends the high frequency current (either Tesla or resonator) in this disease; it may be used for its general effects (p. 135) and also locally by means of the effluve or vacuum electrode (p. 235).

Alopecia, or Baldness.—This condition may be benefited by the use of static electricity. It may be applied by placing a felt cap on the head and then passing a ball electrode connected with the positive pole over this for about five minutes daily. The power of the high frequency current, either from a resonator or secondary of the Tesla coil, to produce a lasting hyperemia makes it of value in the treatment of this condition. It is applied by means of a vacuum electrode held far enough from the scalp for short sparks to pass; they should not be strong enough to be very painful. McKee,[2] by this method, claims very satisfactory results in alopecia occurring in young people (premature alopecia). Vassilides[3] has also obtained satisfactory results.

Another method of stimulating the scalp is by stabile kathodal galvanization. The current strength should be gradually increased to about 6 milliamperes and the application to the bald spot continued until the scalp becomes reddened. Another method is to alternate this plan of treatment with the rapidly interrupted faradic current. *Alopecia areata* should be treated in the same way. Phototherapy has also been used in this affection, but does not seem to be superior to other more easily employed measures. Electricity is only a means of stimulating the scalp, and other measures recommended for these conditions should not be neglected.

Angioma.—This occurs in one of three forms, viz., nævus flammeus, known also as birthmark and port-wine mark, telangiectasis, and angioma cavernosum. The first may vary in size from that of a small pinhead to one sufficiently large to cover the side of the face. Electrolysis probably affords the best plan of treatment. If small, only one

[1] High Frequency Currents, p. 193.
[2] New York Medical Journal, July 28, 1906.
[3] Quoted in Journal of Advanced Therapeutics, June, 1906, p. 314.

sterilized needle of iridoplatinum need be used, this should be attached to the negative pole, the positive pole being at an indifferent point. The needle is then introduced into the growth either perpendicularly, so that it will penetrate the stratum mucosum of the skin, or at the margin of the growth parallel with the skin, and the current gradually turned on until a strength of from 3 to 5 milliamperes is obtained; this should be allowed to continue for a minute or two, when the current is shut off. The growth turns pale about the needle and some frothing will be noticed. Several such applications may be made at a sitting. Another method is to introduce two needles into the growth parallel to each other, one attached to the positive, the other to the negative pole. The current is then turned on as before; after it has caused nearly enough tissue destruction, it should be gradually decreased in strength, reversed, and then increased in strength again before it is finally discontinued; this facilitates the withdrawal of the positive pole. These methods, while efficacious, are too slow for the treatment of large growths, in which case an electrode carrying from ten to twenty needles (Fig. 238) should be used. The needles must be very sharp, and the electrode attached to the negative pole. If it is pressed quickly into the growth, the pain is not great. A fairly strong current, 5 to 10 milliamperes, according to the number of needles, must be employed and the application last from fifteen to twenty seconds. When the growth about the needles blanches, the proper effect has been produced. The blanching passes away after the withdrawal of the needles, but in about twenty-four to thirty-six hours scabs will form where the needles have penetrated, and when these fall off, small punctate cicatrices will be seen. The full effect of the operation will not be apparent for several weeks, after which another operation may be indicated; this should be continued after the interval mentioned until the color of the skin is about normal; further improvement in this is apt to occur as time goes on. In young children a general anesthetic is usually required. If too strong currents or too long applications are used, disagreeable scarring may result. Small nevi may also be destroyed by directing high frequency sparks against them (pp. 268 and 270). The actinic light rays have also been employed with some success, and may be used preferably after electrolysis has been employed. *X*-rays may also be employed (p. 473).

Telangiectasis.—In telangiectasis similar treatment of the enlarged capillaries to that recommended for acne rosacea should be employed. In the form consisting of an enlarged arteriole in the centre from which distended capillaries radiate outward (nævus araneus), the needle should be introduced into the centre of the loop.

Angioma Cavernosum.—Angioma cavernosum, the so-called pulsating blood tumor, should only be treated by electricity when not over one-half inch in diameter, otherwise it should be left to the surgeon. In young children a general anesthetic may be required. Cocaine may be used in older people if desired. When suitable for electric treatment it may be destroyed by either electrolysis or the galvanocautery. If

situated in the face, the former will be found to be of special service. Either one or two needles can be used. If the former, it should be attached to the negative pole and a current strength of from 5 to 10 milliamperes employed. The needle is made to penetrate the growth near its base and the current permitted to flow for a minute or two. Frothing should be noticed at the point of the needle's entrance. If hemorrhage follows the withdrawal of the needle, the application has not been continued long enough. Several punctures may be made at each sitting, allowing sufficient interval between the sittings for the healing of the lesions made at each one. Some operators first make the needle the positive pole and make the application as above described, then after reducing the current without withdrawing the needle it is made the negative pole and an application made as before. If two needles are used, one is attached to the negative, the other to the positive pole; they are then both introduced into the growth, care being taken that the points are not too near together, so as to cause a short circuit. The strength of current is then gradually raised until frothing and blanching appear; the current should then be gradually reduced to zero, the current reversed, and then gradually increased in strength again, to be again gradually reduced to zero, the object of this being to facilitate the withdrawal of the needle attached to the positive pole. This method is more painful than the employment of one needle, and possesses no advantage excepting in large growths. The object of all these methods for treating the various varieties of angioma is to destroy the abnormal tissue, causing the formation of scar tissue and destruction of the blood supply of the growth. Hence, after the growth is destroyed, any dilated capillaries which lead into it should be destroyed by the method advised for telangiectasis; otherwise it may recur. The galvanocautery may be employed to destroy the cavernous angioma, but as this method causes unsightly scarring its use is not recommended.

Atrophy.—This may be either symptomatic, when it is due to either neural, cutaneous, or other lesions, or idiopathic. It may be limited either to the skin and subcutaneous tissues, or the muscles and bones may be involved, as in the condition known as facial hemiatrophy. Treatment of any sort is not very hopeful in this condition, electricity being as useful as any. The galvanic current may be employed so as to traverse the nerves leading to the abnormal part, and to stimulate the sympathetic ganglia in the neighborhood. Static electricity may be employed in the shape of either sparks or the breeze. If the muscles are involved they should be stimulated with the faradic current. General faradization, central galvanization, and high frequency currents may be used for their general tonic effects. Care must be taken in the local treatment not to use too strong currents.

Carbuncle.—The galvanic current has been recommended to abort carbuncles, boils, and other suppurations of the skin and subcutaneous tissue. The brush discharge may also be used (pp. 245 and 248). In

cases that are fully developed, the galvanocautery has been employed to destroy the diseased tissue. Surgical measures would seem to be preferable.

Chloasma.—Stabile galvanization with the kathode over the pigmented area may be tried. Electrolysis as advised for pigmented scars (see below) can also be employed.

Cicatrices of the Skin.—In those scars that are elevated above the surrounding skin and when there is not sufficient tissue near them to allow of their excision and the suturing of the fresh wound so made, some benefit may be derived from electricity. Electrolysis can be employed by introducing one or more needles attached to the negative pole into the hypertrophied tissues. Shrinking and thinning of the scar will usually follow such a course of treatment. In *depressed or atrophic scars* the appearance can be improved by a superficial cauterization by means of electrolysis. The needle attached to the negative pole should be introduced horizontally just below the superficial layer of the skin and the current continued sufficiently long to separate this from the underlying layers. These applications must be continued until the entire surface has been gone over, the object being to remove the superficial epithelial layer. After this has been done the denuded surface should be dressed with an impermeable dressing, such as adhesive plaster or liquid gutta-percha. This dressing should be continued for a long time, being reapplied if necessary, after which it will be found that the scar has risen and assumed a more normal appearance. If it has not, the electrolytic treatment and dressing may be repeated. The *telangiectatic scar,* in which dilated capillaries are seen, should be treated in the manner advised for telangiectasis.

Pigmented scars may be improved by making punctures at regular intervals with a needle connected with the kathode, and using a current strength of from 4 to 6 milliamperes. It is not desirable to entirely destroy the dark color, as the leaving of small areas of pigment prevents the dead white color which would otherwise result, and hence a more natural color is produced. The galvanocautery can also be used.

Cornu Cutaneum, or Cutaneous Horns.—After the avulsion of the growth, the galvanocautery is the best means of cauterizing the base. If this is too small for the cautery to be used, electrolysis, with a strong current (10 to 12 milliamperes), and the negative pole should be employed.

Dermatalgia.—This is really a hyperesthesia, and similar treatment should be used (p. 366).

Dermatitis.—Both dermatitis venenata (ivy poisoning) and dermatitis congelationis (chilblain) may be treated with either the faradic or galvanic currents. If the latter is used a large positive moist electrode should be applied to the affected area and a current of from 10 to 15 milliamperes applied for twenty minutes three times weekly.

Dermatolysis.—Dermatolysis, or circumscribed hypertrophy of the skin, may be subjected to electric treatment, the galvanocautery being used to remove the cutaneous folds.

Eczema.—In chronic eczema, where stimulation is required, the negative pole of the galvanic current or the brush discharge of the static machine (p. 245) may be used for that purpose. The patient should be connected with the negative side of the machine. If a dry stick is used, it must be dampened from time to time. The electrode must be moved constantly over the surface being treated. Sparks from a resonator, or Tesla coil (p. 237), a vacuum electrode (Fig. 197) being employed, may prove useful. Snow[1] states that these methods are also useful in moist eczema. Treatment should be given daily if possible. The itching is much relieved by these methods. The general tonic and metabolic effects of general faradization, central galvanization, and high frequency currents by autocondensation may be utilized.

Elephantiasis.—Silva Aranjo, a Brazilian physician, has cured a large number of cases by electrolysis combined with galvanism and faradism. His method is to pass from one to three needles, insulated to within a short distance of their points, deeply into the tissues; they are then connected with the kathode of the galvanic current, which is increased in strength to 20 milliamperes. This is continued for ten minutes. This procedure is repeated at intervals of about a week. During the intervening time daily applications of the combined galvanic and faradic currents are made for fifteen minutes. In connection with this treatment, massage and bandaging with an india-rubber bandage are employed. Mann has treated a case successfully by employing the galvanic current with the kathode on the sole of the foot and the moistened anode moved about on the surface of the limb. The strength of current was from 5 to 10 milliamperes.

Epithelioma of the Skin.—When situated where it cannot be excised, it may be treated by curetting the diseased tissue away and then cauterizing the raw surface with the galvanocautery. This stops hemorrhage and is not followed by pain (see also p. 288). After *x*-rays have been used and the surface shows no disposition to heal, either the brush discharge (p. 245) or high frequency sparks (p. 237) may be employed as a stimulant for periods during which the *x*-rays are suspended.

Fibroma Molluscum.—Fibroma molluscum, or, as it is also termed, molluscum fibrosum, is best treated by the removal of the tumors with a galvanocautery snare, the loop being thrown around the pedicle, the wire being then made red hot. Small and flat growths may be extirpated by means of electrolysis, a sharp needle insulated to near the point being attached to the kathode and then introduced into the growth.

Filaria Medinensis.—Filaria medinensis, or guinea-worm disease, is rare in this country, being a tropical disease. The best treatment is the employment of the galvanic current, one pole being placed on the head or protruding extremity of the worm and the other being held in

[1] High Frequency Currents, p. 180.

the hand of the patient. In one reported case the current was continued for an hour, traction being made on the worm in the meanwhile until it is removed. By this means the parasite is benumbed so that within an hour or so it is removed, while under ordinary conditions weeks are required.

Furuncle.—Furuncle, or boil, may be aborted in its incipiency by introducing into its apex a needle attached to the galvanic negative pole and using a current of from 6 to 8 milliamperes for about five minutes. The early use of the brush discharge (p. 245) from a static machine or high frequency sparks (p. 237) may also be employed with success in aborting boils and also in felons and other abscess processes. It is claimed that by their use local stasis is overcome, the tissues are softened, and thus blood is allowed to flow freely through the area and phagocytosis facilitated (p. 139).

Glanders or Farcy.—Electricity may be used in the local treatment of the lesions of this infectious disease. The galvanocautery may be used to cauterize the ulcers and thus destroy the virus, those occurring in the nostrils being reached by means of the different electrodes devised for that purpose (Fig. 305).

Herpes Simplex.—It has been claimed that a mild galvanic current, one electrode being placed over the seat of the lesion, will abort the trouble.

Herpes Zoster.—The neuralgic pains of this disease are best treated by passing a constant galvanic current through the affected nerves for fifteen minutes daily. The anode should be placed at the spinal exit of the nerve and the kathode at its termination on the chest. A current strength of from 5 to 10 milliamperes should be used, and several applications may be made daily if necessary. The local application of the wave current will also relieve the pain and, if used early, possibly prevent the appearance of the lesions. If, however, the eruption has appeared, the use of sparks from a resonator attached either to a static machine or coil will hasten recovery (Snow). A glass vacuum electrode should be used.

Hyperesthesia.—Hyperesthesia of the skin is frequently due to organic disease of the nervous system; it may, however, be apparently idiopathic. Electricity may be of great service for the relief of this condition. The galvanic anode with a mild current may be applied to the sensitive area, as advised for the treatment of pain elsewhere (p. 302). Static insulation (p. 257) and the static breeze (p. 244) may also be tried. If sedative measures fail, stimulating ones sometimes give relief. Such measures are the galvanic kathode with a strong current, the faradic current, using the dry brush electrode (Fig. 117), and the administration of either static sparks (p. 227) or the high frequency current (Tesla or resonator), by means of the effluve or vacuum electrode (p. 235).

Hypertrichosis.—Hypertrichosis or superfluous hairs are best treated by electrolysis; in fact, this is the only method which insures permanent

results without injury to the skin. For the operation are required a large comfortable chair, such that the patient can throw the head back in easily, fine needles, preferably of iridioplatinum, and a needle holder (Fig. 237), an ordinary moist electrode covered with either sponge or absorbent cotton, a means of procuring the galvanic current with a milliamperemeter and current controller in the circuit, and, in the case of fine or light colored hairs, a magnifying lens which can be attached to the eye of the operator, and a pair of forceps for removing the hair (Fig. 282). The patient should be placed in a good light, preferably that from the north, and the moist electrode held in one hand; the needle attached to the negative pole is inserted at the side of the hair into the follicle; when properly done it should meet with no resistance and cause practically no pain; if resistance is experienced another attempt should be made. The circuit is then closed either by pressing the arrangement on the handle, or, if the handle has not such a device, by the patient grasping the electrode with the hand. A current of from 1 to 3 milliamperes is employed, and in a few seconds the destruction of the follicle will be indicated by frothing. To be sure it is destroyed the current should pass from ten to twenty seconds, according to the coarseness of the hair. The circuit is then opened and the hair grasped by the forceps; it should not require any force for its withdrawal; if resistance is experienced the operation must be repeated. From a half-hour to an hour, during which twenty-five to fifty hairs, according to their character, can be removed, should constitute a sitting. It is not well to attempt more, for the operation is most trying to both the eyesight and patience of the operator, and as soon as fatigue is experienced good results are not obtained. Some burning pain is experienced by the patient, which, however, usually becomes less after a few hairs are removed, the skin apparently becoming benumbed by the current. Redness and slight swelling may follow the removal of the hair, which will soon disappear. It is not advisable to treat at one sitting hairs which are too close together, as scarring may be thus produced. It is well before beginning the operation to arrange the current controller so that the proper strength of current is obtained; this can be done by the operator grasping the moist electrode and placing the needle against the skin of his hand, then gradually increasing the current strength until the required number of milliamperes is reached; the controller is then left at that point. Some operators recommend grasping the hair with the forceps, and while thus holding it inserting the needle and closing the circuit. Excepting in the case of long curly hairs, the auther has not found this method as convenient as the one first described. The froth and pallor about the hair operated upon will indicate it so that it can be easily grasped by the forceps after electrolysis is completed. It has been recommended by A. H. Piri to use needles insulated to within $\frac{1}{16}$ inch of the point. This may be done by holding the needle red hot in a piece of shellac, except for the $\frac{1}{16}$ inch near the point. Scarring he claims is thus avoided. Massey

claims that the pain can be much diminished by moistening a small area of the part to be operated on with a 10 per cent. solution of cocaine; take out four hairs at the corners of a space $\frac{3}{4}$ inch square and allow the solution to flow lightly over each point of application, after which the neighborhood of the four punctures becomes anesthetic and hairs within it may be removed painlessly. Excepting in the case of very nervous people this seems hardly necessary. With the most skilful treatment, a certain proportion of the hairs will return; these, however, are usually finer than those removed, and excepting in the case of excessively fine ones may be alternately destroyed by succeeding operations. *X*-rays have also been used for this purpose, and while they will cause disappearance of the hair, there are objections to the method, and electrolysis is much safer and hence preferable.

Ichthyosis.—The unsightly elevations in ichthyosis hystrix may be removed by the galvanocautery. Goler reports a cure by daily exposure for twenty minutes to the light from a 20-ampere arc lamp, passed through two 8-inch plano-convex lenses mounted in pairs.

Keloid.—Electrolysis, it has been claimed, has cured some cases of this disease. The method advised by Hardaway is to employ a strong needle attached to the negative pole of the galvanic battery. Punctures should be made both from side to side and perpendicularly through the growth. Hayes recommends that in addition it be plunged into the tissues for some distance about the tumor, so as to destroy the diseased vessels going to it. Neiswanger[1] advises the use of thiosinamin introduced into the scar tissue by cataphoresis. His formula is thiosinamin, 45 grains; glycerin, 2 drams; water, 6 drams; sodium chloride, 5 grains. A current of from 3 to 5 milliamperes is allowed to flow for eight minutes, and the operation is repeated once in five days.

Lentigo, or Freckles.—These may be sometimes made to disappear by applying the anode and using a constant current of from 4 to 6 milliamperes. Hardaway recommends, when they are very black, that each freckle be touched with the electrolytic needle attached to the negative pole. Care must be taken that the needle does not penetrate to the deeper layers of the skin, otherwise scarring will result.

Lichen.—In both lichen ruber and lichen planus, measures that act as tonics, such as general faradization, central galvanization, static insulation, and high frequency applications may be tried. High frequency and static currents locally may also prove of benefit either by means of the brush discharge (p. 245) or effluve or by friction with a large glass vacuum electrode (p. 238). Itching is much relieved by these measures. Infiltrated plaques may have sparks applied to them.

Lupus Erythematosus.—The galvanocautery, using a broad electrode heated barely red, may be used to sear the diseased tissues, after which

[1] Wisconsin Medical Recorder, November, 1908.

an antiseptic dressing should be applied. After ten or twelve days the eschar separates, leaving a pale, smooth surface. When telangiectasis is present it should be treated as recommended elsewhere. (See Angioma and Acne Rosacea.) One of the most successful modes of treatment is the employment either of high frequency or static currents. The static brush discharge may be used or the effluve or vacuum electrode. Another method is to hold a carbon electrode almost in contact with the skin until a vesiculation with a rupture of the skin and a serous exudation are produced (pp. 235 and 245). Destruction of the tissues is, however, not always necessary.

Lupus Vulgaris.—The galvanocautery may be used to destroy the diseased tissue; if the growth is extensive general anesthesia may be required. The static brush discharge or high frequency current by effluve or vacuum electrode (pp. 235 and 245) can be tried. Either the x-rays or phototherapy appear to be a preferable plan of treatment (pp. 288, 475, and 476).

Milium.—As the formation of milia is due to the closure of the orifices of superficial glands in the skin, the treatment consists in opening the little tumor and expressing its contents; then, to prevent its recurrence, the secreting surface should be destroyed by electrolysis, a coarse, blunt needle connected with the negative pole being introduced into the opening and a current strength of from 3 to 5 milliamperes employed for about five seconds.

Mole.—*See* Nævus Pigmentosus.

Molluscum Epitheliale, or Molluscum Contagiosum.—After the contents of the tumors are evacuated electrolysis should be employed as advised for milium. In some cases it may be necessary to use the galvanocautery, a superficial cauterization only being made. After the lesions have been destroyed radiotherapy may be used to prevent recurrence.

Molluscum Fibrosum.—*See* page 365.

Morphea.—The galvanic current passed through the abnormal areas has been recommended. Most authorities have seen no benefit result from this procedure, and such is the experience of the author.

Nævus Lipomatodes.—If the growth is pedunculated it may be removed by the galvanocautery, as recommended for molluscum fibrosum (p. 365). If not, electrolysis should be employed, as advised under Angioma Cavernosum (p. 362).

Nævus Pigmentosus, or Pigmentary Mole.—Electrolysis as advised for angioma is the best mode of treatment. If the pigmented area is large and flat, electrolytic tattooing, as described for pigmented cicatrices (p. 364), gives good results. High frequency currents, using fine sparks, applied to the growth have been recommended (fulguration) (pp. 268 and 270). After the growth is removed, no matter by which method, the exposure of the area to x-rays is useful to prevent recurrence. These growths are especially liable to become malignant.

Nævus Pilosus, or Hairy Mole.—The hairs found on the growth should first be removed, as advised for the treatment of hypertrichosis (p. 366).

A stronger current may be required to attain this end than is required for hairs elsewhere. This may also suffice to destroy the mole; if it should not, it should be subjected to electrolysis, as advised for angioma. The galvanocautery may be employed for that purpose, also high frequency currents, as advised for pigmented moles.

Nævus Verrucosus, or Warty Nevus.—This wart-like growth should be treated by electrolysis, the needle being inserted under the growth parallel to the skin and a current of 5 to 10 milliamperes employed for ten minutes. If necessary, the operation should be repeated after an interval of two weeks. High frequency currents also answer the purpose, used as described for pigmented moles.

Pruritus.—Either the galvanic, faradic, high frequency, or static current may prove of benefit in this neurosis. If the former is used, a large, moist electrode, attached to the positive pole, should be applied stabile to the affected part and a current strong enough to produce a feeling of warmth and redness of the skin employed for several minutes. The faradic current is applied in a similar way, using the rapidly interrupted current. The static current may be used in the form of either sparks or the breeze applied to the affected region. Excellent results are obtained by using high frequency currents, using either effluve or contact friction with a large glass vacuum electrode (p. 238). Pruritus in any situation or when a symptom of any skin or other affection is relieved by this means. Any cause, if found, should, of course, be removed if possible.

Psoriasis.—Shoemaker claims to have achieved good results from the static current, "especially where infiltration has occurred and there is obstruction to the local circulation by inflammatory deposits, which are speedily caused to be absorbed by these applications." High frequency currents, applying the effluve vacuum electrode to the lesions, may be tried.

Sarcoma of the Skin.—This may be treated by the x-rays, and if small by short sparks from the resonator, using a pointed carbon electrode (p. 237, Fig. 192, *c*).

Scleroderma.—This may be treated as advised for morphea. Schwimmer states that he obtained success in one case after eighteen months' treatment by subaural galvanization (p. 226).

Scrofuloderma.—Either central galvanization, general faradization, static or high frequency currents may be employed for their general tonic effects. It is stated that after such treatment the skin acquires more tone, looks better, and the roughness is reduced.

Seborrhea.—In the oily form of this disease, galvanism may be employed with advantage. A moist electrode attached to the negative pole is applied to the diseased area, the strength of current being 5 to 10 milliamperes.

Sweating.—In excessive sweating, whether manifested as *hyperidrosis* or *bromidrosis*, either the static or high frequency current may be used for its tonic effects (pp. 134 and 135).

Tattoo Marks.—Electrolysis can be used to remove these. The needle attached to the negative pole is penetrated below the surface and a current of about 5 milliamperes employed after the inflammation so produced has subsided; other similar operations should be performed if necessary.

Syphiloderm.—Hayes states that phoresis (p. 271) may be utilized to hasten the disappearance of syphilitic eruptions, especially the papular, tubercular, and gummatous varieties. The method employed is to saturate the positive pole with a soluble salt of mercury (p. 276), as, for instance, a 1 to 1000 solution of the bichloride. This is then placed over each lesion in turn for several minutes. Previously the area to be treated should be first well washed with soap and water and then with either alcohol or ether in order to remove as much as possible the natural oil of the skin. Either stronger or weaker solutions than that mentioned above may be used. In situations where the early disappearance is of importance this method is of value.

Tinea.—The various varieties of tinea, viz., tinea versicolor, tinea favosa, tinea sycosis, and tinea tonsurans, may be treated by phoresis. The scales should first be removed by soap and water, then the positive pole is saturated with a solution of some parasiticide, as a 1 to 1000 solution of bichloride of mercury, and applied to the diseased area. A current of about 10 milliamperes should be used and a sitting lasting from twenty to thirty minutes. The operation should be repeated at intervals of two days until cure results. Radiotherapy is also useful in causing the disappearance of the lesions of these affections; as, however, it does not cause the destruction of the fungi, the usual antiseptic measures are needed in conjunction with it. High frequency brush discharges may also prove of service. Non-parasitic sycosis may also be treated with advantage with the x-rays.

Ulcers, Chronic.—These may be stimulated if necessary by the galvanocautery, either applying it to the indurated edges or slightly scarring the surface with a flat electrode heated to a dull red. A weak solution of bichloride of mercury may also be used for this purpose, being driven into the tissues by phoresis. The application of the brush discharge or high frequency sparks from a Tesla coil or resonator, using a vacuum electrode, may be useful, especially if there is much induration around the ulcer. This is made rapidly to disappear. Treatments should be given every two or three days. Sluggish bed sores may be treated by this method (see also pp. 227, 237, 245, and 248).

Urticaria.—The itching may be relieved by the methods advised for pruritus.

Verruca, or Wart.—These may be removed by electrolysis, passing a needle connected with the negative pole under the wart at its junction with the healthy skin. If the wart is not raised above the skin, the needle may be inserted perpendicularly. Several sittings may be required. Venereal warts may be removed by the galvanocautery, which prevents hemorrhage and does not produce much pain. The use

of the static and high frequency currents, as in treating moles, is of use (p. 369), as is also the application to the wart of the moist galvanic anode, with a current strength of from 4 to 6 milliamperes. This may be wet with a saturated solution of sulphate of magnesia.

Vitiligo.—By the application of a moist electrode attached to the negative pole of the galvanic battery to the pigmented areas surrounding the white patches, some of the pigment may sometimes be made to disappear, thus rendering the disfigurement less noticeable. The current should be as strong as can be borne.

Xanthoma.—Electrolysis may be used to remove the growths, the method to be employed being that recommended for nevus (p. 369).

CHAPTER XXV

DISEASES OF THE GENITO-URINARY ORGANS OF THE MALE

Electricity has been utilized in the treatment of various forms of impotence, spermatorrhea, strictures of the urethra, chronic inflammation and enlargement of the prostate gland, chronic epididymitis, enuresis, and paralysis of the bladder.

Impotence.—In cases of *psychical* or *nervous impotence, i. e.*, those in whom the sexual power is normal but who are incapable of performing the sexual act from a morbid fear that they are not competent, measures which will make a mental impression are, of course, indicated. Among these electricity holds a prominent place. This may be used in such a way that it will cause erections and hence persuade the patient that he can have them when necessary. Benedikt, Schulz, and others[1] advise the use of the galvanic current for this purpose, employing the following method: The positive pole is placed over the lumbar vertebræ, and with the negative pole the perineum, spermatic cords, and penis are successively stroked. Weak currents should be employed, daily sittings of two or three minutes being given for from six to ten weeks. Ultzmann (*loc. cit.*) prefers the faradic current, employed as follows: "One pole, a metallic staff about 6 cm. long, is placed in the rectum. With this pole so situated, the other electrode is applied successively over the bulb of the urethra, and right and left over the ascending rami of the pubis. In this manner, contractions of the musculus bulbocavernosus and of the musculi ischiocavernosi are produced, consequently of that muscular apparatus which favors the erection of the penis and promotes the ejaculation of semen." The length of the sitting should be from five to ten minutes and daily if possible. Onimus[2] recommends introducing one pole into the rectum to the height of the seminal vesicles, and with the dry brush stimulating the testicles and penis. He remarks that an erection may often be produced during the treatment. In these cases the high frequency current may be of great value. Freund reports good results using autoconduction (p. 262). Local application by means of the vacuum electrode (p. 238) to the penis and along the spine may have a good mental effect.

In cases of *actual impotence*, with poor or no power of erection, and also when the semen is ejaculated without force, the faradic current, with one pole in the rectum and the other on the perineum, is an excellent

[1] Quoted by Ultzmann, Genito-urinary Neuroses, translated by Allen, p. 38 et seq.

[2] Quoted by Vecki, Sexual Impotence, p. 253.

mode of treatment.[1] The rapidly interrupted current must be used and strong enough to cause bulging of the perineum from muscular contraction. Another method is to place one electrode in the perineum

Fig. 319

Uterine or urethral electrode, with spiral, flexible, insulated stem.

Fig. 320

Urethral electrode.

and the other, by means of the urethral electrode previously sterilized (Figs. 319 and 320), in the prostatic urethra. Vecki[2] recom-

[1] It must be understood that while electricity is of great service in these cases, it must not be depended upon exclusively. Other indications must be met, for which the reader is referred to books upon these subjects.

[2] Loc cit., p. 252.

mends the galvanic current, placing the negative pole over the lumbar cord and the positive pole, stabile, successively on the upper and lower surfaces of the penis, to the testicles, perineum, and the spermatic cord downward from the inguinal ring. If a more powerful action is desired, the positive pole should be placed over the lumbar cord and a sterilized urethral electrode attached to the negative pole introduced into the prostatic portion of the urethra. Weak currents for from two to five minutes should be employed about once a week, for in this method a certain amount of cauterization is produced by the electrolytic action of the current. The object of all these methods is to strengthen the muscles which control erection. If the penis is cold, shrivelled, cyanotic, and anesthetic, the dry faradic brush applied to it is most efficacious in improving its circulation and sensibility. In cases of *hyperesthesia of the prostatic urethra*, with frequent nocturnal emissions, the positive pole of the galvanic current applied stabile for several minutes successively to the perineum and over each spermatic cord, the negative being over the lumbar cord, is often of benefit.

Many of the cases of premature ejaculation are due to *chronic prostatitis*. In such either the static wave or high frequency currents are indicated. Snow[1] prefers the former, excepting in infectious cases. The patient should lie on his side on the insulated platform and hold the insulated handle, to which is attached a metal electrode (Fig. 278), firmly against the gland. It may also be held in place by means of an x-ray tube holder. The patient should be connected with the positive side of the machine (Fig. 259), the negative being grounded. The length of the spark gap will depend upon the acuteness of the case. It is usually well to begin with a spark gap of less than 1 inch, which may be increased in chronic cases to as much as 4 inches. If an insulated platform sufficiently large to recline upon is not at hand, an electrode devised by Snow may be used upon which the patient can sit. The application should be made daily for the first ten days and last from ten to fifteen minutes. The rectal vacuum electrode (Fig. 197) may also be used, attached either to the static machine or to the resonator or Tesla coil. If connected with the static machine, it should be attached to the positive pole except in infectious cases, when the negative is preferable, as it has greater actinic properties. These methods, beginning with very mild currents, may be employed in *acute prostatitis* if pus is not present. If of infectious origin, the high frequency current, applied with a vacuum electrode, which may be insulated (Fig. 200) so as to obtain greater concentration of the current, may be used. The electrode may be attached to one terminal of the coil, while a flat metallic electrode is attached to the other and placed firmly upon the bare abdomen. These methods are of no service in malignant and tubercular cases, in the former of which the x-rays may be tried.

[1] Medical Record, January 13, 1906; American Journal of Dermatology, March, 1908. Quoted in Journal of Advanced Therapeutics, May, 1908, p. 261.

Casper[1] recommends, associated with other measures, the rapidly interrupted faradic current in *chronic prostatitis,* one pole in the shape of a metal electrode being placed in the rectum and the other being placed over the pubes.

Spermatorrhea.—The plan of treatment recommended for cases of hyperesthesia (p. 375) may be tried. In conjunction with these measures, in both impotence and spermatorrhea, either general faradization or the high frequency or static currents may be used as general tonics (pp. 250, 257, and 261).

Chronic Urethritis.—Chronic urethritis has been treated by the cataphoric diffusion of copper and mercury ions (p. 392). The surface of a 20 French copper urethral sound is amalgamated with mercury (p. 396). The parts of the sound not intended to be active are insulated with a thin coating of sealing wax. After introducing, it is connected with the positive pole by twisting the bared metal end of the cord about it. The dispersing electrode, in the shape of a large pad (p. 150), may be placed either on the back or abdomen. A current strength of from 5 to 10 milliamperes for ten minutes is used. A silvered copper catheter may also be used in the same way. Armstrong[2] has devised a special electrode for the ionization of either silver, zinc, or copper in this disorder.

Strictures of the Urethra.—Two methods[3] of treating stricture of the urethra, each depending upon the electrolytic action of the current (p. 113), have been advocated. The first is that of Dr. Robert Newman, in which mild currents are used, and depends upon, as Newman states, "galvanochemical absorption;" the other, that of J. A. Fort, of Paris, which he has termed "linear electrolysis." Excellent results by each of these methods are claimed by the originators and others, but they have not been generally accepted by genito-urinary surgeons.

For the carrying out of his method, Newman has devised what he terms his urethral electrodes, consisting of four separate sets, as follows:

1. The egg-shaped set. These are employed in most cases. They have a short curve, with an egg-shaped metallic bulb at the working end; the rest of the instrument is insulated. The sizes range from 11 to 30 of the French scale.

2. The acorn set. These are for use in the first 6 inches of the urethra; they are straight and the metallic bulb is acorn-shaped.

3. The tunnelled electrode (Fig. 321), designed for use in bad, tortuous strictures. The curve is shorter and the egg-shaped bulb is tunnelled, so that they can be introduced over a filiform guide.

4. The combination electrode. This is a tunnelled electrode and catheter, and is designed for cases where there is retention of urine.

The technique of the operation is as follows: The location and

[1] Genito-urinary Diseases, translated by Bonney, p. 305.

[2] Journal of the American Medical Association, July 2, 1910, p. 27.

[3] This statement refers to those in modern use. Electrolysis was employed for this purpose as far back as 1847. For the literature of this subject consult Medical and Surgical Electricity, by Rockwell, p. 572, and International System of Electrotherapeutics, second edition, p. G. 94.

caliber of the stricture are first determined by the usual methods. An electrode is selected which is three numbers larger than the size of the stricture. It is then lubricated and introduced into the urethra until it is arrested by the stricture. It is well, in order to be sure that the bulb has reached the desired spot, that before it is introduced a small india-rubber ring be slipped over the shaft of the electrode, the same distance from its end as the stricture is from the meatus, as determined by the previous measurement. After its introduction the electrode is connected to the negative pole and the positive placed at some indifferent point. The current is then gradually increased until the milliamperemeter indicates a strength of not more than 5 milliamperes; less will often suffice. The electrode must be held steadily against the stricture, but no force should be used. Newman states that the stricture soon yields and the instrument will pass through in a few minutes. This should be repeated for each stricture until the instrument reaches the bladder. The instrument is then gradually withdrawn until

Fig. 321

Newman's tunnelled catheter electrode.

the first stricture is repassed, when the current is gradually reduced to zero and the electrode removed. In from one to two weeks the operation is repeated with an electrode two or three sizes larger than the previous one. Newman has reported 200 cases successfully treated by this method. Others have also reported successes, but the majority of observers are not favorable to the method.[1]

Fort's method,[2] which he terms "linear electrolysis," is described by him as follows: The "electrolyzer," which consists of a long, flexible, and slender rubber bougie, with a smooth and not sharp platinum blade projecting from the middle, which is connected with a platinum wire that runs through the centre of the bougie and which can be connected with the battery, is passed into the urethra until the blade is engaged in the stricture. It is then connected with the negative pole and the positive placed on the thigh or over the pubes. After this is done the current is turned on and increased to a strength of about 10 milliamperes.

[1] On the Curability of Urethral Strictures by Electricity, by E. L. Keyes, New York Medical Journal, October, 1888; also, The Limitations of Electrolysis as a Therapeutic Agent in Organic and Spasmodic Strictures of the Urethra, with Cases, Journal of Cutaneous and Genito-Urinary Diseases, July, 1888, also Medical and Surgical Electricity, Rockwell, p. 573.

[2] Electrolyzer for the Surgical Treatment of Strictures, J. A. Fort, New York Medical Journal, November 16, 1895, p. 625: also his book entitled Traitement des rétrécissements par l'électrolyse linéaire.

The operation is painless and requires about thirty seconds. The usual antiseptic and aseptic precautions should be taken before the operation. Very little or no bleeding should result. A sound should be passed on the third and fourth days after, and this should be done about once a month thereafter. This method, which theoretically seems more rational than Newman's method, has not met with much favor among genito-urinary surgeons.

Ravogli[1] states that he has obtained satisfactory results from electrolysis in causing the absorption of "infiltrated patches" which produce *gleet.* He employs an electrode devised by himself, consisting of a sound insulated to within a short distance of its tip with rubber. The sizes used vary from 18 to 24 French. The sound attached to the negative pole is introduced into the infiltrated point, and the current increased to a strength of from 12 to 20 milliamperes; while the current is passing the sound is moved gently up and down. The positive pole is held in the hand. He states that no pain is produced, and that the gleety discharge is first increased and then "subsides in some days." Two or three applications at intervals of several days may be needed.

Another method has recently been advocated by Silhorst.[2] After dilating the constriction by means of sounds to a 23 French scale, the urethra is thoroughly irrigated with a solution of mercury oxycyanate. Oberländer's urethroscope, corresponding with Nos. 23 to 30 French, is then inserted, passing along the entire length of the stricture. After which the tube is withdrawn until the surface of the stricture shows in the opening. The needle, ending in a strong platinum point from 1½ to 2 cm. in length and insulated until quite close to the point, is forced to a depth of ½ to 1 cm. into the fibrous tissue. This is made the negative pole of the galvanic battery, the positive, a large flat one, being placed at an indifferent point. A current of from 4 to 6 milliamperes is employed for three minutes. After the operation the urethra is irrigated as before. Treatments at first are given three times a week, later only once a week. During the period of treatment a bougie is introduced once a week, followed by irrigation with a nitrate of silver solution.

Epididymitis.—The galvanic current may be employed to cause absorption of the exudate in chronic epididymitis. The negative pole should be placed over the tender point at the bottom of the scrotum and the positive at some indifferent point. A current strength of 1 milliampere is first employed for five minutes; after several days this may be increased to 2 milliamperes, and finally to 3. Sittings every other day should be given. High frequency currents (Tesla or resonator) applied by means of a vacuum tube to the affected part may be tried in non-malignant and tubercular cases.

Orchitis.—In traumatic and infectious cases, excepting when tubercular, malignant, or abscess is present, the high frequency current

[1] New York Medical Journal, January 18, 1902, p. 97.

[2] British Medical Journal, March 24, 1906.

may be used. A vacuum tube (Fig. 197), preferably with a concave surface, is held against the upper part of the gland for five or ten minutes, and as the tissues soften is moved downward over the entire gland until soft ened. This may require a half hour or longer.

Hypertrophy of the Prostate Gland.—Electrolysis, the galvanocautery, and high frequency currents have been employed in the treatment of this affection. The following methods are advocated:

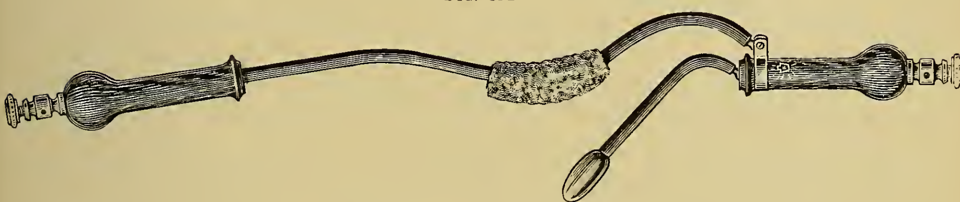
A. Electrolysis. (1) Electrolysis by mild currents. (2) Massey's method with strong currents. (3) Galvanopuncture through the rectum.

B. Galvanocautery. (4) Newman's slow method. (5) Bottini's rapid method in one seance. (6) The use of the galvanocautery to remove the tumor after the operation of suprapubic cystotomy has been performed.

Of these methods, electrolysis with mild currents and Bottini's are most in vogue at this time, and in certain cases the latter especially is of service.

For electrolysis with mild currents, which was advocated by Dr. J. V. Shoemaker, the so-called prostatic electrolyzer (Fig. 322) is probably

Fig. 322



Prostatic electrolyzer. (Shoemaker's.)

the best instrument. The negative pole is a metal bulb which is introduced into the rectum against the prostatic enlargement, while the positive, a moist electrode, is held against the perineum. A current strength of 10 or more milliamperes may be used and the treatment given every two or three days.[1]

Bottini's Method.—This, as has been said above, is a valuable method, and is the only one that is to any extent advocated by genito-urinary surgeons. In a paper read before the American Association of Genito-urinary Surgeons, May 1, 1901, Dr. Orville Horwitz, of Philadelphia, reached the following conclusions: "(1) Success following the Bottini operation depends on having perfect instruments, a good battery, the necessary skill, and the employment of a perfect technique. (2) In suitable cases the Bottini operation is the safest and best for the radical cure thus far devised for the relief of prostatic hypertrophy. (3) It is often very efficacious in advanced cases of obstruction as a palliative measure, rendering catheterism easy and painless, relieving

[1] For further information, if desired, see International System of Electrotherapeutics, second edition, p. G. 136.

spasm, lessening the tendency to constipation, and improving the general health. (4) It is of special service in the beginning of obstructive symptoms, and may be regarded as a means of preventing catheter life. (5) It is indicated in all forms of hypertrophy except where there is a valve formation or where there is an enormous growth of the three lobes, associated with tumor formation, giving rise to a pouch, both above and below the gland. (6) When the bladder is hopelessly damaged, together with a general atheromatous condition of the bloodvessels, associated with polyuria, results are negative. (7) Pyelitis is not a contraindication. (8) The character of the prostatic growth has no bearing on the results of operation."

Casper[1] asserts that the operation is only indicated when there is residual urine. When there is retention, he thinks it should only be done after this has lasted three months. Some cases in whom the first operation was ineffectual were benefited by a second. If catheterization is not difficult, and can be done under proper precautions, he does not advise the operation; otherwise he does. It is indicated when there are frequent attacks of acute retention of urine. It is contraindicated in feeble patients with arteriosclerosis, if there is bilateral pyelitis or pyonephrosis. Hemorrhage and sepsis are dangers, hence the operation is dangerous if cystitis is present. In this connection see also page 381.

Freudenberg[2] has collected 683 cases, which show a mortality of $5\frac{1}{2}$ per cent. of 666 cases; no benefit was obtained in $6\frac{1}{3}$ per cent., more or less benefit in 88 per cent., of which $\frac{2}{3}$ were cured so that they could urinate normally, while $\frac{1}{3}$ received but slight benefit.

The bladder is first washed out and emptied and the posterior urethra is anesthetized by means of eucaine or cocaine. Freudenberg advises that the bladder be distended with air; some, however, operate with the bladder empty. The former is the safer plan. An assistant should watch the cooling apparatus of the instrument (Fig. 323) to see that the flow of water does not cease. The instrument is introduced and the concavity of the instrument turned toward the gland; it is then slightly withdrawn so that its concave surface will hug the prostate. The cooling apparatus is then started and the current turned on. Fifteen seconds should be allowed for the blade to heat, when it is projected to the required extent by means of the screw on the handle. After a sufficient groove has been burned, the cautery knife is returned to its sheath, the heat being increased while this is being done. After the male blade has been withdrawn into the female blade, the current is turned off. A second and third furrow can be burned in a similar manner. Bottini burns three furrows—a moderately deep one toward the rectum, a shallow one toward the pubes, and a deep one into the lateral lobe which is the most enlarged. Freudenberg (*loc. cit.*) says that the cut should not exceed $4\frac{1}{2}$ to 5 cm., and usually from $2\frac{1}{2}$ to $3\frac{1}{2}$ cm. will suffice. To measure the proper length for the incision, after the introduction of

[1] Genito-urinary Diseases, p. 354 et seq.
[2] Archiv f. klin. Chirurgie, 1901, Band lxi, Heft 4.

the instrument the beak is turned backward and the finger in the rectum measures the distance from this to the pars membranacea, and $\frac{4}{5}$ of this distance will represent the proper length for the posterior cut and $\frac{1}{2}$ for the lateral. The operation requires about five minutes, the patient afterward being able to urinate at will, and can get out of bed on the second day. Hemorrhage rarely may occur when the slough separates. In cases of hemorrhage, very purulent urine, and where frequent catheterization is necessary because of difficulty or pain, Freudenberg advises that a catheter be retained in the bladder for a time after the operation. An objection to the operation[1] is that the neck of the bladder is also damaged and that the cicatrices are apt to contract, causing stenosis of the vesical neck. Sepsis has been produced.

Deaver[2] states that while the operation possesses advantages in selected cases where the dangers of shock and postoperative pulmonary complications seem great, these advantages are more than compensated by its uncertainty of cure and the dangers of sepsis.

Fig. 323

Prof. Bottoni's instrument for burning the prostate. It is composed of a hollow sound in which is concealed a large platinum galvanocautery knife, requiring about 40 to 50 amperes to operate. The sound is kept cool by forcing water through it, so that no action will arise from heat except where the platinum knife is exposed. A cut may be made of any desired length with absolute precision, as the knife is operated with a graduated screw device at the handle.

The instrument has been modified by Freudenberg (*loc. cit.*), also by Jacoby.[3]

Both the static wave current and high frequency current (Tesla or resonator) may be tried as advised for chronic prostatitis (p. 375).

Enuresis Nocturna.—This, when not due to either an actual or reflex irritation, but to a derangement of the innervation of the bladder, may sometimes be benefited by the use of the faradic current. One pole may be placed over the pubes and the other over the perineum or sacrum. If this method does not suffice, a catheter electrode (Fig. 320) insulated to within a short distance of the end should be introduced into the bladder, the other pole being placed on the abdomen. Grimm[4] reports good results by placing one pole in the rectum and the other on the thigh and using the galvanic current with a strength of from 2 to 5 milliamperes. This should be done for five or ten minutes each night before retiring.

Paralysis of the Bladder.—*See* page 300.

[1] Eugene Fuller, Medical Record, November 19, 1898.
[2] Pennsylvania Medical Journal, April, 1910, p. 539.
[3] Deutsche med. Wochenschrift, September 18, 1902.
[4] Internat. klin. Rundschau, February 29, 1893.

CHAPTER XXVI

DISEASES OF THE GENITO-URINARY ORGANS OF WOMEN

Various kinds of electrical treatment have been advocated from time to time, for most all of the diseases of the genital organs of women. Many of the methods advocated by enthusiasts have probably been harmful, so much so that all electrical methods are looked upon with distrust by some gynecologists and a valuable method of treating certain disorders has been neglected. A conservative opinion of the conditions in which it is valuable is that of Dr. B. C. Hirst, of Philadelphia, who advises its use in amenorrhea, menorrhagia, and metrorrhagia, especially when due to fibroid tumors, undevelopment of the uterus, and for weakness of the vesical and rectal sphincters. Franklin H. Martin, of Chicago, who is also conservative, in addition to these, advises its use under certain conditions for endometritis, fibroid tumors, dysmenorrhea, and pelvic inflammatory exudates.

In using electricity for the relief of gynecological conditions, strong currents are frequently necessary; it is, therefore, essential that a good current controller (pp. 159 and 395) and a reliable milliamperemeter be in the circuit. For the same reason, as we wish to cause as little pain as possible, it is essential that the indifferent electrode should be large. For this purpose (when very strong currents are employed) one of those described on page 194 should be used.

All intra-uterine and intravaginal treatment should be carried out under strict aseptic and antiseptic precautions. The vagina being first swabbed out with tincture of green soap and then a solution of bichloride of mercury, and the electrode sterilized by boiling. If, however, the insulating material is such that will not stand boiling, this may be done by means of formaldehyde gas in one of the many forms of sterilizers devised for this purpose.

DISORDERS OF MENSTRUATION

Amenorrhea.—Amenorrhea, if due to anemia, may be treated by utilizing the general tonic properties of either general electrification (p. 257), the static wave current (p. 259), or high frequency currents applied by means of autocondensation or autoconduction (p. 262). When a local tonic and stimulant is desired, Hirst advises the galvanic current. The kathode, by means of an intra-uterine electrode (Fig. 324), is introduced into the uterus, and the anode, a large pad (p. 194), placed on the abdo-

men. He advises that the application be made every other day, beginning one week before the expected period, with a current strength of from 10 to 15 milliamperes, for from ten to fifteen minutes. A. Lapthorn Smith advises the rapidly interrupted faradic current applied by means of a bipolar intra-uterine electrode (Fig. 325). Pitcher[1] advises spinal galvanization, the anode, a pad 4 by 6 inches, wet with soap and water, being applied to the upper spinal region, and the kathode, a pad 6 by 8 inches, is applied over the lumbar region. The current strength should be from 10 to 40 milliamperes, applied for twenty minutes, three times weekly. This can be alternated with the positive pole on the back and the negative over the abdomen. When there is no improvement at the end of two months, he adds intra-uterine faradization. Either a unipolar (Fig. 324), or dipolar electrode (Fig. 325) may be used. In the case of the former a pad (p. 194) should be placed on either the back or the abdomen, the rapidly interrupted current being used for from ten to fifteen minutes.

In cases in which the patients have an excess of adipose tissue, and, in fact, in others, the static wave current (p. 258) may be used with advantage, a metal vaginal electrode, connected with the negative pole being introduced into the vagina against the uterus or, if the patient is a virgin, into the rectum, a rectal electrode (Fig. 278) then being used.

Fig. 324

Inflexible insulated intra-uterine electrode.

During the first month treatment should be given daily, beginning with a small spark gap and increasing it gradually until the limit of tolerance, which may be six inches. It should last from fifteen to twenty minutes. If the negative pole is too painful, the electrode may be attached to the positive, the negative being grounded. In all cases, if anemia exists it must be treated by proper remedies.

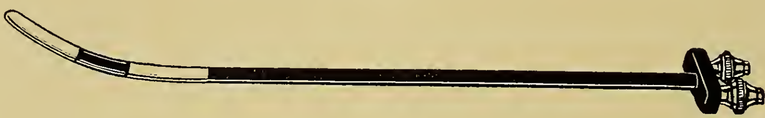
Dysmenorrhea.—Electricity has been highly recommended for *obstructive dysmenorrhea.* When due to non-development of the uterus, either the faradic or sinusoidal currents, slowly interrupted, may be tried. A bipolar electrode (Fig. 325) is used, which should be pliable so that the proper curve can be given to it. It should be introduced so that one pole will exert its influence on the body and the other on the neck of the womb. The application should last five minutes, be as strong as the patient can comfortably bear, and made about every other day. Martin says that this method will almost invariably relieve the most aggravated case of this type after a month's treatment. It should be continued until the uterus develops into a normal size and condition. Hirst endorses it. The static wave current is also useful. A long,

[1] Journal of Advanced Therapeutics, February, 1909. p. 63.

curved, metal electrode should be introduced into the rectum, pressed against the uterus, and connected with the positive pole, the negative being grounded; otherwise the treatment is conducted as advised for using the same current for amenorrhea (p. 383), the high frequency current, a rectal vacuum tube, which is preferably insulated to within two inches of its end, being introduced into the rectum. If the patient is married, treatment by the vagina is more convenient (Figs. 197, 200, and 202).

In *dysmenorrhea* due to *stricture* or *stenosis* of the *uterine canal* from any cause the galvanic current is advised, a unipolar electrode (Fig. 324) being introduced into the uterus. Martin[1] advises that this be the positive pole, and says the results of electrical treatment are as follows:

Fig. 325



Bipolar uterine electrode for faradic current.

1. The mechanical effect of inserting two or three times a week for a month a sound that quite fills the canal insures drainage for the uterus.
2. The positive intra-uterine galvanism (*a*) acts as a local sedative, (*b*) contracts local bloodvessels, (*c*) dries the endometrium by attracting the acids through electrolysis, (*d*) acts as a powerful antiseptic, (*e*) still further dries or depletes the tissues by cataphoresis, and (*f*) causes tanning of the tissues by the salts or copper formed by a combination of the ions of the positive pole with the soft copper of the electrode.
3. Further good results are to be expected from the general systemic tonic effects of the galvanism. In cases in which endometritis does not co-exist, the negative pole is preferable in the uterus in this form of dysmenorrhea, a current of 10 milliamperes being passed for five or ten minutes. The indifferent electrode, in the shape of a large pad (p. 194), should be in the abdomen. The physiological action of the kathode would seem to indicate that it would be the preferable one when it is desired to remove an organic obstruction, as is the case when a stricture of the cervix exists. In *membranous dysmenorrhea* the method advised above by Martin has given good results.

For *neuralgic pains* which occur during the menstrual period without apparent cause electricity may sometimes prove beneficial. The treatment should be carried out between the periods, and either the galvanic, faradic, sinusoidal, or the galvanic and faradic combined may be used. When the galvanic current is employed the anode is introduced either into the uterus, vagina, or rectum, and the kathode, in the shape of a large pad (p. 194), placed on the abdomen. A current of from 15 to 30 milliamperes should be employed every other day. If relief is not

[1] Electrotherapy, Jacoby, p. 281

produced after a couple of months' treatment, a strong, rapidly interrupted, faradic current should be tried, with either a bipolar uterine (Fig. 325) or vaginal electrode (Fig. 327). As these patients are

Fig. 326

Vaginal electrode, partly insulated.

Fig. 327

Bipolar vaginal electrode, insulated.

frequently neurotic and neurasthenic, general faradization, static insulation, and other tonic measures may be employed in addition to the local treatment.

For patients of this type Snow recommends the static wave current. One of several methods may be employed: Either a rectal electrode (Fig. 278) may be placed in the rectum and the sitting last for two minutes

daily, during the intermenstrual period, or a large abdominal electrode (p. 259) may be placed over the pubic region, or an electrode (Fig. 326) can be placed in the vagina and pressed well into the posterior fornix. If either intrarectal or intravaginal treatment is used, the spark gap should be from two to six inches long. In young girls the intrarectal plan of treatment is often of great service.

High frequency currents (Tesla or resonator) with a vaginal or rectal vacuum electrode (Fig. 197) will also give good results.

Menorrhagia and Metrorrhagia.—In this condition Hirst advises the use of the galvanic current with the anode in the uterus and the kathode, in the shape of a large pad (p. 194), on the abdomen. A current strength gradually increased to at least 60 milliamperes should be employed for ten or fifteen minutes, then gradually decreased. It is indicated in cases due to either chronic endometritis or fibroid tumor. Also in subinvolution, after abortion with the retention of small pieces of decidua. (See Endometritis and Tumor.)

DISORDERS OF THE UTERUS

Chronic Endometritis.—In cases which for any reason cannot be curetted the galvanic current may be employed as follows: A copper intra-uterine electrode, such as shown in Fig. 324, is introduced into the uterus and attached to the positive pole, the negative, in the shape of a large pad (p. 194), being placed on the abdomen. The current is then gradually increased to not exceeding 30 milliamperes, allowed to remain at the maximum strength for five minutes, and then decreased. This application may be made every second day. If the electrode becomes adherent and difficult to remove, it should be made the negative pole and the current gradually increased as before for one minute, after which it can be easily withdrawn. Massey advises the use of the carbon-bulb electrode of Apostoli (Fig. 329), the largest one capable of being inserted being used and a current of from 40 to 100 milliamperes used. The electrode should be held in this position for two or three minutes, then the current is reduced in strength and the electrode withdrawn a little, and the process repeated. This "sectional cauterization" is continued until the bulb impinges on the internal os. Massey also advises mercuric cataphoresis (p. 392) in these cases, and says that the action of the positive pole in the uterus is rendered of greater alterative and microbicidal effect thereby; it also has the advantage of lessening the caustic effect of the current on the mucous membrane. Where currents of 50 milliamperes or less are employed, the technique is the same as above described, excepting that the metallic end of the copper electrode is amalgamated by first dipping it in an acid and then in mercury. It must be freshly amalgamated for each application (p. 396). The action of either copper, silver, or zinc may be also utilized in this way by having the electrode made of the desired metal. The

use of such oxidizable metal electrodes as the anode and the consequent transfer of their ions is preferred in these cases by most electrotherapeutists, the action of the metal being obtained and the production of scar tissue avoided.[1] The surface of the electrode must be freshened and sterilized, although the application itself is antiseptic. The treatment should last from five to fifteen minutes and be made about once in three or four weeks, preferably in the middle of the menstrual month. Twenty milliamperes should be the average current strength, and the patient should rest for an hour or so after the treatment.

Fig. 328

Flexible and insulated intra-uterine electrode.

Fig. 329

Apostoli's carbon-bulb electrodes.

Pelvic Inflammatory Exudates.—The absorption of these can sometimes be caused by the use of the galvanic current. It should only be employed in chronic cases and where there is reason to believe that an abscess does not exist. The kathode covered with wet absorbent cotton should (Fig. 326) be introduced into the vagina so that it is against the mass, the anode, consisting of a large pad, placed on the abdomen, and a current gradually increased to 50 milliamperes employed for five minutes. The first applications may have to be weaker than this. The treatments should be given about three times weekly, and may have to be continued for from three to six months. If the exudate completely surrounds the uterus, an intra-uterine electrode (Fig. 328) should be used. The action of oxidizable electrodes at the anode, as described on page 386, may be used in pyosalpinx. In such

[1] Journal of Advanced Therapeutics, June, 1906, p. 269, and Lancet. July 10, 1909.

cases some pain and discomfort may result after the treatment. This may at times be relieved by the use of the rapidly interrupted faradic current, using an intravaginal electrode (Fig. 327). The static wave current applied as advised under dysmenorrhea has also been recommended for chronic pelvic cellulitis and ovaritis. High frequency currents (Tesla or resonator) with vaginal vacuum electrode (Fig. 197) may also be used.

Fibroid Tumors.—The treatment of these tumors by galvanism, especially by puncture, as practised by Apostoli, Massey, and some others, has not become popular in this country. There are, however, certain cases in which its use by the intra-uterine method may prove valuable. Martin,[1] who had had a large experience in both the surgical and electrical treatment of these growths, gives the following rules for the selection of cases in which electricity may be used with advantage. To these, however, he says that there may be exceptions.

1. In bleeding fibroids in women approaching the menopause.
2. In all inoperable cases.
3. In incipient fibroids in women over forty years of age.
4. In all bleeding fibroids of the smooth, interstitial variety, without other symptoms than hemorrhage.
5. In all cases (not accompanied by pelvic pus accumulation) in which operation is refused.

Hirst advises the galvanic current for menorrhagia due to small interstitial fibroids (p. 386). The styptic action of the anode may be increased, utilizing electrolysis and cataphoresis, as described on page 386. Martin (*loc. cit.*) says that the typical case for electrical treatment is one of the interstitial variety, in which the new tissue is uniformly distributed throughout the uterus, enlarging it to a symmetrical tumor and proportionately expanding the uterine canal. Those not exceeding from 6 to 8 inches in length and 3 to 4 inches in lateral diameter are best suited for the treatment.

The objects to be gained are: (1) To cause electrolysis by passing through the growth as strong a current as can be borne, without severely cauterizing the tissues at the poles. (2) To lessen bleeding by the coagulating action of the acids liberated at the anode, this effect still further being enhanced by formation of styptic copper salts by the combining of the acid and the copper of the electrode, which are driven into the tissues by the cataphoric action of the current. (3) The cure of the endometritis which usually co-exists with fibroids. The technique of the operation is as follows: After an antiseptic vaginal douche the patient is placed on her back upon a table, the buttocks being drawn to the edge and the feet supported by stirrups. After the size, shape, and direction of the uterine canal have been determined by the use of flexible sounds, a long copper electrode (Fig. 328) is similarly shaped and passed to the bottom of the uterine canal and the

[1] Electrotherapy, Jacoby, ii, 271.

vaginal portion insulated by slipping over it a muff of rubber. This is attached to the positive pole of the battery and the negative pole, as a large pad (p. 194), placed on the abdomen. The current is then turned on and gradually strengthened until it reaches 100 or even 200 milliamperes. The indications for the proper strength of current are, first, the feelings of the patient, and next, if no suffering is caused, the length of the intra-uterine portion of the electrode, 50 milliamperes being allowed for each inch of an electrode of ordinary diameter that is within the uterus. The maximum current should be passed for five minutes and the applications made every other day, excepting when there is menorrhagia the treatment may be omitted during the menstrual period. The symptoms, such as pain, reflex disturbances, and leucorrhea, soon disappear and the general health improves, and after several months' treatment the tumor will be found to have diminished in size. After the symptoms disappear the treatment should be stopped, to be resumed if they reappear.

In cases where the uterus is very large the entire endometrium cannot be acted upon at one application with a current sufficiently strong to produce good effects. In such cases the strength of the current should be about 25 milliamperes for each square centimeter of active electrode, hence to apply a current of 100 milliamperes, the electrode is insulated to within 4 square centimeters of its distal end. The depth of the canal being measured, the distal four centimeters are acted upon, the next day four more, and so on until the entire surface has been treated.

Cases that are *inoperable* or *complicated,* as when there is severe purulent metritis and endometritis, associated often with the discharge of gangrenous masses from submucous fibroids, the patients frequently being septic and poorly nourished, may be treated, with frequent relief of the symptoms, by the introduction of the copper electrodes, as described on page 388, and the employment of 200 milliamperes of current. Antiseptic douches should be used in conjunction morning and evening.

Cases in which the uterine canal is so distorted that the electrode cannot be introduced, and which for any reason are deemed inoperable by the surgeon, may sometimes be relieved of many of their symptoms by placing a vaginal electrode (Fig. 326), attached to the negative pole, posterior to the tumor and the large pad attached to the positive pole being so placed that the largest diameter of the tumor is placed between it and the vaginal electrode. Currents of from 50 to 100 milliamperes may be thus passed for five minutes every other day. If a vaginal electrode cannot be employed, a rectal one having an active surface of at least 8 centimeters should be passed well up behind the tumor and similar applications made.

Vaginitis has been treated with the galvanic current by means of hydro-electric douches (p. 256), the action of which may be further enhanced by replacing the platinum wire of the vaginal water electrode (Fig. 223) with one of either copper, silver, or zinc, or mercury; any of

these may be amalgamated with mercury (pp. 386 and 396). The ions of these metals being thus distributed over the inflamed membrane act as antiseptics and astringents. Iodide of potassium and iodine may be also used if indicated (p. 271). Three or four quarts of water should be used. The current strength should be from 1 to 20 milliamperes. Weak currents should be employed first. Simple metal electrodes may be used. High frequency currents (Tesla or resonator), by means of a vaginal vacuum electrode, may also be employed.

DISEASES OF THE URETHRA AND BLADDER

Urethral Caruncles.—Urethral caruncles are often easily removed by the galvanocautery snare. If it is not sufficiently pedunculated to admit of this procedure, it may be cauterized with a blunt-pointed electrode. Snow advises the use of high frequency currents, a urethral vacuum tube being employed; treatment should be daily for ten or twelve minutes. If obtained from a static machine, the connection should be made to the positive side, the negative being grounded.

Urethritis.—Urethritis due to any cause may be treated with metal electrodes of either copper, silver, or zinc, as advised for vaginitis.

Polypi.—Urethral polypi may also be removed by the galvanocautery snare.

Stricture.—Strictures of the female urethra may be treated by electrolysis, the method advised being similar to that of Newman (p. 376). If the stricture is spasmodic, high frequency currents applied by means of a urethral vacuum tube (Fig. 197) may be successful.

Atony.—In atonic conditions of the *urethral* and *vesical* sphincters, which frequently occur in women who have borne many children, great benefit is derived from the daily use, for about three minutes, of the faradic current, either a bipolar electrode being introduced into the urethra, or a unipolar urethral electrode (Fig. 319) being similarly used, the other being placed on the abdomen over the bladder.

Nocturnal Enuresis.—This may be treated as in male children (p. 381).

Neuroses.—In neuroses of the bladder, as the irritable bladder of hysteria, relief may be obtained by the use of the rapidly interrupted faradic current, one pole in the urethra, the other on the abdomen, or one pole on the abdomen, the other on the perineum.

Paralysis.—Paralysis of the *bladder* is treated as described on page 300.

Paralysis of the *anal sphincter* may be here mentioned, as it frequently occurs associated with gynecological conditions. It may be treated with the faradic current, one electrode (Fig. 278) being placed just within the anus, the other over the sacral region.

THE USE OF ELECTRICITY IN OBSTETRICS

Hyperemesis Gravidarum.—This troublesome condition may sometimes be relieved by the use of either the galvanic or faradic current. If the former is used, the anode should be placed on the abdomen and the kathode at an indifferent point. If the latter, it should be rapidly interrupted, the electrodes being placed in the same locations as advised for the galvanic current.

Ectopic Gestation.—Electricity has been employed to kill the embryo in this condition. It is only applicable before the sac has ruptured, and not after the fourteenth week of gestation, the embryo after this time being too large to allow of its disintegration and absorption with safety to the mother.

Either the galvanic or faradic currents may be employed, the latter, rapidly interrupted, being preferable. One electrode is introduced into either the vagina or rectum so that it is against the sac, and the other placed on the abdomen. The current strength should be as great as can be borne, and applied for ten or fifteen minutes. The treatment should be repeated on alternate days until diminution in the size of the mass shows that fetal death has occurred. During the treatment the patient should be kept in bed. After death has occurred, the galvanic current, the kathode being in the vagina against the mass, should be used to promote absorption.

Abdominal section is preferred in these cases by most obstetricians because of the uncertainty of the diagnosis, the possibility of the mass being due to an acute inflammatory condition and the length of time required, which adds to the danger of rupture. If, however, the diagnosis can be made soon enough, the method is worthy of trial.

Abortion.—Electricity, either the galvanic or faradic current being used, has been advised to produce abortion when such is found to be necessary. Either an intra-uterine or vaginal electrode may be used, the other being on the abdomen, or a bipolar intra-uterine electrode can be employed. If the galvanic current is used it must not be interrupted and the kathode is introduced within the uterus (Fig. 324). A current strength of from 30 to 50 milliamperes is employed for fifteen or twenty minutes. Similar methods have been advised to set up uterine contractions when the fetus is known to be dead. Other methods, however, are surer and safer.

CHAPTER XXVII

MISCELLANEOUS

TREATMENT OF MALIGNANT GROWTHS BY MERCURIC CATAPHORESIS

THIS method was devised by Dr. G. Betton Massey, of Philadelphia, and by its use he claims very gratifying results.[1] Only growths on the surface of the body or within accessible cavities, as within the mouth, rectum, and at the cervix uteri, are proper for the treatment. It is also best applied in effective dose in regions that are not close to important centres of innervation of the heart and respiratory apparatus on account of the very strong currents usually necessary. Of course, complete success can only be expected when metastasis to internal organs has not occurred. The basal facts of the process, according to Massey, are that in the utilization of the electrolytic and phoretic powers of a strong electric current (pp. 113 and 114) for dissolving and ionizing zinc points or needles coated with mercury and thrust into the growth, a quantity of ionized mercury and zinc may be interstitially diffused throughout a tumor in a few minutes that will be sufficient to kill all malignant cells and their accompanying germs, if the latter be present, and that by prolonging the process sufficiently these microbicidal substances will be driven farther than the apparent boundaries of the growth in sufficient strength to kill outlying colonies and lines of dissemination in the immediate neighborhood, without serious detriment to the healthy tissues in this situation. Thus, when a current is passed through the ionized or dissociated body of molecules constituting the basal constituents of a living growth, a powerful directing movement is given to the ions everywhere present, the oxygen, chlorine, and other anions being impelled toward the anode (the electrode within the growth), where they give up their negative charge, becoming simple atoms. These atoms, being no longer in the condition of ions, attack the least refractory elements of opposite sign at hand, in this case the mercury and zinc of the electrode. The metals being now in solution in water, and thus ionized, are but lightly held by the oxygen and chlorine, and being themselves charged with positive electricity, become kations, and seek at once the negative pole in a distant part of the body. The oxygen and chlorine remain near the active electrode (anode), forming water and other compounds, while the mercury and zinc ions radiate outward,

[1] Journal of Advanced Therapeutics, 1907, p. 389 et seq.; Conservative Gynecology and Electrotherapeutics, fifth edition.

uniting and disuniting in turn with the oxygen and chlorine of the tissues as they spread, destroying the vitality of cells and germs as they proceed, since zinc and mercury in the ionized state are poisonous to protoplasm. Electrodes of iron, metallic arsenic, copper, and silver, the last two coated with mercury, have been tried, but the best results have been obtained with zinc and mercury.

For the major operation currents of from 300 to 1500 milliamperes are employed continuously from fifteen minutes to one hour or more. Therefore the 110-volt direct current employed for incandescent lighting is the preferable source of power. If the alternating current is the one

Fig. 330

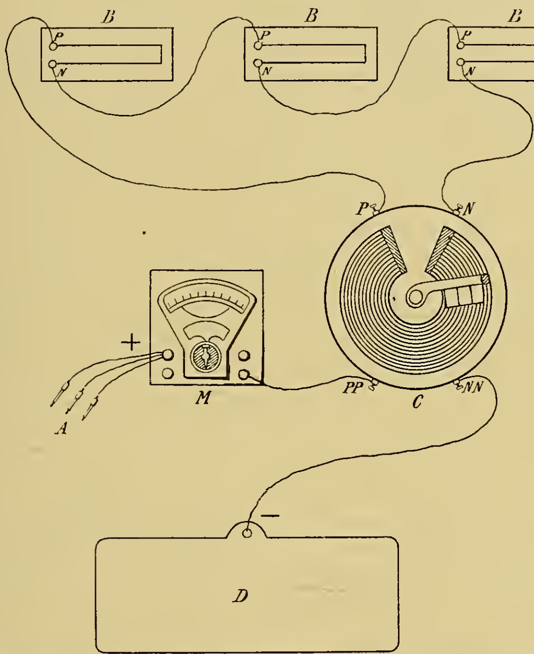
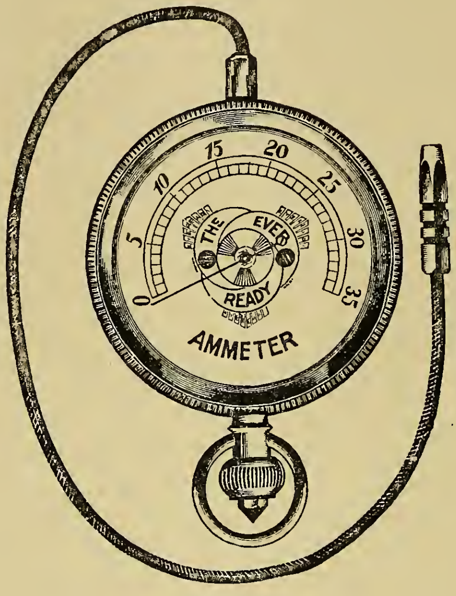


Diagram of arrangement of portable apparatus for monopolar cataphoric operation. (Massey.)

at hand, it must be transformed to the direct by a motor transformer (Fig. 332). When the street current cannot be used, sufficient current can be obtained from forty to sixty freshly manufactured dry cells. When cells are used, they must be connected as shown in Fig. 330. The voltage of the cells should not fall below 8 or 10 amperes when short circuited through a small ammeter (Fig. 331). If any cell falls below 5 amperes, it should be thrown out and replaced. When the direct street current is used, each new lamp socket used must have the polarity of the conducting cords tested. This is done as follows: Before inserting the plug into the socket unwind two or three inches of the end of the cord, bare the end of each wire, and bend them apart

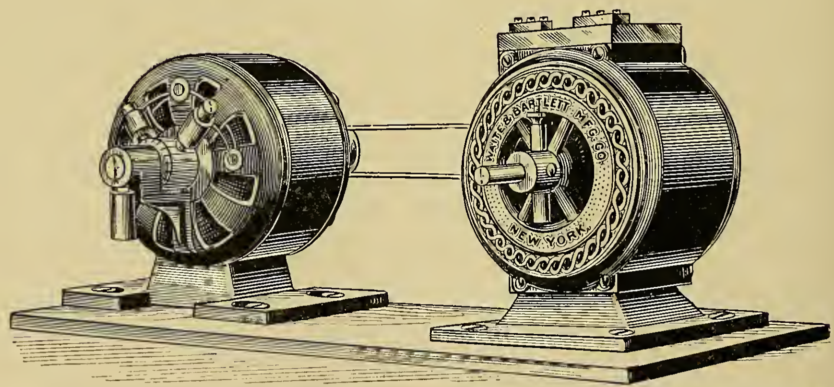
so that they will not come into contact. Now insert the plug into the socket, turn on the current, and put both wire ends into water in which

Fig. 331



Pocket ammeter.

Fig. 332

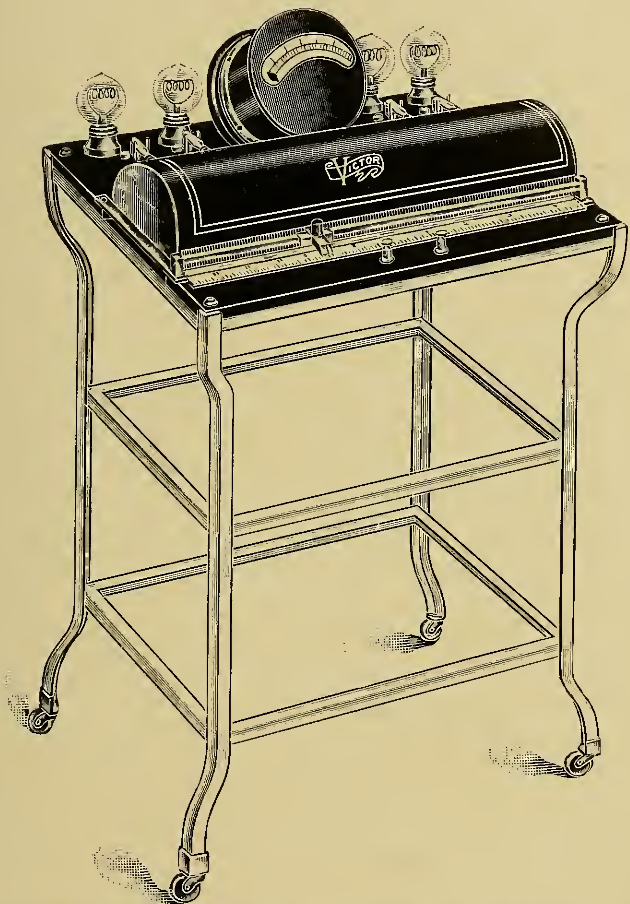


Motor generator to run on the alternating current and to give a direct current for galvanic purposes. This apparatus consists of an alternating current motor and a direct current dynamo, mounted on a heavy oak base and connected by means of a round belt.

some table salt has been dissolved. More gas will be observed coming off at the negative pole than the other. When a transformer is necessary, as in the case of the alternating current, it must be connected with

a $2\frac{1}{2}$ ampere 110-volt direct current dynamo (Fig. 332). The polarity of the connection is ascertained as described above. The current must be controlled by an efficient controller which will permit a current to be increased gradually from zero to 2000 milliamperes. The use of the shunt lamp lessens the voltage, which is desirable in making minor applications in painful situations, as 2 milliamperes is

Fig. 333



Massey's ionization table for major and minor ionic surgery, showing the form of controller used by him.

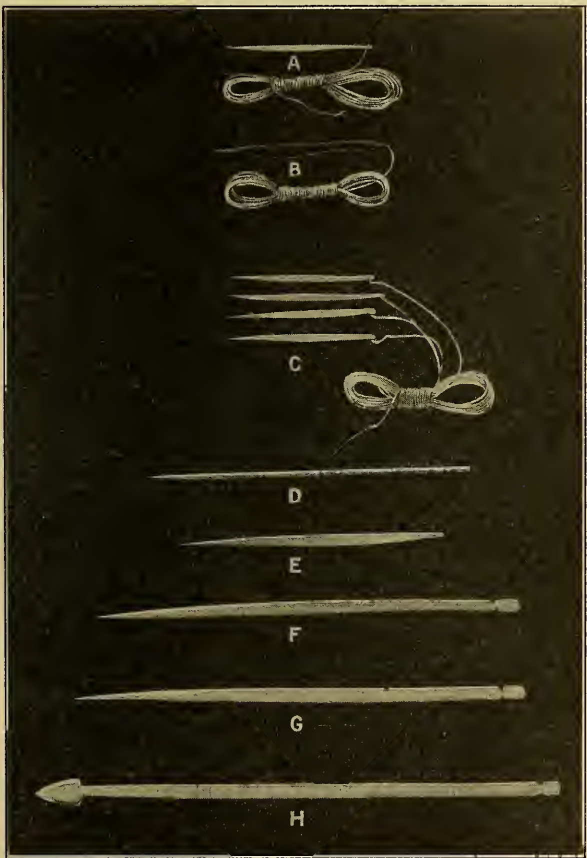
less painful from four volts than from the entire voltage of the circuit. The series lamp should not be used when employing a cell battery. Both lamps should be turned off when very strong currents are being used. When moderately strong (to 250 milliamperes) the series lamp is turned in the circuit and the shunt lamp out. Both lamps are turned in when mild currents are desired. A reliable meter with two

scales, 0 to 1000 milliamperes and 0 to 2000 milliamperes, is essential. All apparatus must be aseptic, therefore made of metal (Fig. 333). A kaolin or clay pad (p. 194) is used as the dispersing electrode. For major operations each pad should measure 14 by 20 inches and possess a uniform thickness of one inch. They should be kept permanently immersed in water in a copper sterilizer; before use the water should be brought to the boiling point. One of the large pads is sufficient for 500 to 600 milliamperes when applied to a broad skin surface, as the back. If a stronger current is used, two pads placed sideways must be used, and the wires connected to the metal plates should be carried together to the negative binding post of the apparatus. The connection of the wire with the metal plate must be covered with a small piece of rubber cloth before placing it on the pad. The active electrodes are made of zinc of various shapes and sizes (Fig. 334). They may be cut by the operator from sheet zinc of a thickness of $\frac{1}{64}$ inch and connected with the conducting cord by baring its end and wrapping it tightly about the electrode and clamping it with a pair of pliers. Before insertion into the growth the end is amalgamated by dipping the end into dilute sulphuric acid, mercury, and water in turn. If for any reason it is desired, the electrode can be insulated (Fig. 334, *B*) by coating it with sealing wax, except at the top. Small electrodes should be used only once, as they become brittle. In any event the electrode must be given the desired curve and insulated if desired before being amalgamated.

Unless contraindicated, a general anesthetic is desirable in the major operation and the patient prepared for the operation in the usual way. Vigorous scrubbing, however, of the affected part is not required. Before administering the anesthetic the apparatus should be tested, after which the controller must be brought back to zero. The electrodes should be attached to the wires ready for use. The operating table is prepared by placing a folded blanket over it, on this is laid a waterproof sheet, on which the metal plate with wire attached and guarded, as shown above, is laid, when the patient is nearly anesthetized, the warm clay pad is laid upon the plate (p. 195). Care must be taken to see that the pad is of uniform thickness and is everywhere in conjunction with the patient's back, and that no metal touches the patient. If a microscopic examination of the growth is desired, a small piece must be excised before the current is turned on. The active electrode being inserted into the growth, the current is gradually turned on, the patient's pulse and respiration being carefully watched, until 150 milliamperes is reached. If more than one electrode is used, they are then introduced in various locations and the current increased until 100 to 150 milliamperes per point are being employed. It is well, however, not to employ too many at once. As the color about the electrode changes, *i. e.*, to a whitish gray, or a softening of the induration is felt, the electrode is withdrawn, reamalgamated, and inserted at a fresh point until the entire growth has been treated. In external growths special attention should be paid to the periphery and enlarged glands. This usually takes,

according to the size, from twenty minutes to an hour. When the application is made near the heart or to the head and neck, the pulse and respiration must be very carefully watched, and not too strong currents used. Massey states that the following maximum current strengths may be safely used by this (monopolar) method. To the head, mouth,

Fig. 334



Massey's zinc-mercury cancer electrodes (two-fifths natural size). *A*, No. 1, minor electrode; *B*, No. 2, minor electrode insulated with sealing-wax; *C*, leash of medium-sized external electrodes; *D*, minor mouth, uterine or rectal electrode, uninsulated; *E*, major breast or external electrode; *F* and *G*, major mouth, uterine, or rectal electrodes; *H*, spade-pointed major uterine or rectal electrode. (Williams, Brown & Earle.)

throat, and neck, 300 to 400 milliamperes; to the left breast, minor monopolar applications only; to the right breast and thorax, generally 400 to 800 milliamperes; below the waist, 800 to 1600 milliamperes. After the treatment the current is slowly turned off and a dry sterile dressing applied. By using the bipolar method stronger currents may

be applied to growths of the head, neck, and left breast. In using this method the negative pole is placed on top of the growth and a number of

Fig. 335

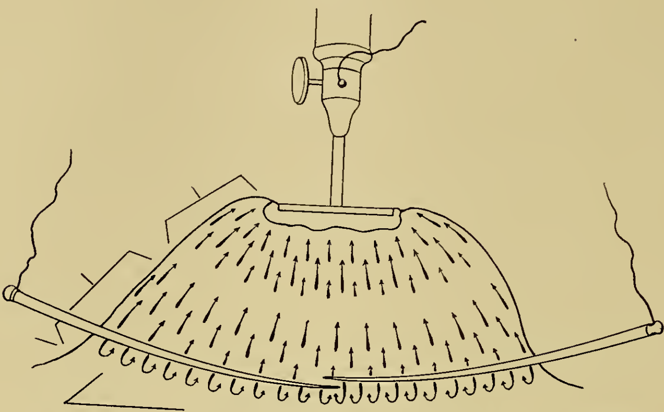


Diagram of cataphoric and anaphoric zones in bipolar operation. (Massey.)

positive electrodes are introduced into the periphery of the growth (Fig. 335). The indifferent electrode may consist of the ordinary large sized covered disk electrode (Fig. 113) held in the centre of the growth

Fig. 336

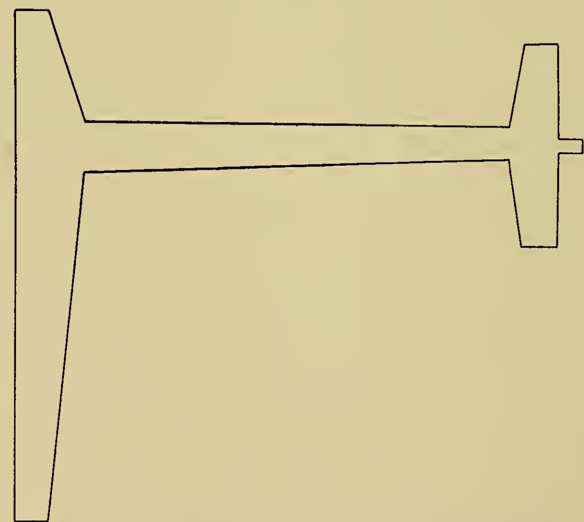


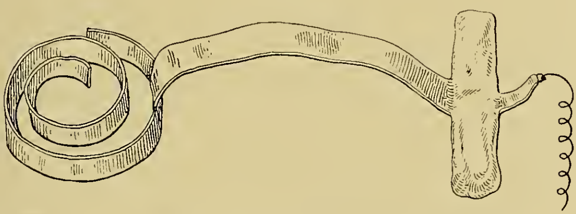
Diagram of piece of plate zinc used in making bipolar negative electrode (Massey.)

by an assistant or by the self-retaining electrode devised by Massey. This may be made of sheet zinc, cut in the shape shown in Fig. 336,

and bent into the shape shown in Fig. 337. The cord is attached to the opposite end from the spiral, and then all but this heavily insulated with sealing wax. A strip of thick gauze is placed between the turns of the spiral and kept wet with equal parts of sulphuric acid and water (to neutralize the alkaline liquids which form at the negative pole). The spiral end rests on the centre of the growth and the insulated shank is held on the healthy skin with adhesive plaster. It may be well at times to follow this treatment with a mild monopolar application. In cavities, as the rectum, a spade-shaped electrode (Fig. 334, *H*) covered with cotton moistened with the acid and water may be used as the negative pole and held against the growth.

Little pain is felt after the operation. The dressing may have to be changed more or less frequently after the first few days, according to the amount of serous discharge. If odor appears, a moist bichloride dressing may be used. The slough separates from the seventh to the twenty-first day, according to the nature and size of the growth. After the separation there may be some risk of secondary hemorrhage in localities near large bloodvessels. In some instances these may be

Fig. 337



Negative electrode for bipolar cataphoric operation in external situations. (Massey.)

ligated a few weeks previous to the cataphoric operation. A second operation should be done if complete destruction has not occurred. For the minor operation, general anesthesia is not required, cocaine or Schleich's fluid being used, depending whether the place being treated is denuded of skin, or injection underneath the skin is required. An ordinary good graphite controller and milliamperemeter (Figs. 46 and 105) will answer, as extremely heavy currents are not used, from 2 to 80 milliamperes being sufficient. Smaller zinc electrodes are used, and if a sinus lead to the part to be treated, unless it is desired to affect its walls also, an insulated electrode (Fig. 334, *B*) should be used. In malignant conditions, the applications should last about thirty minutes; in tubercular, fifteen will be sufficient. Otherwise, the technique is similar to the major operation.

Suppurating Sinuses.—Suppurating sinuses have been also treated by this method, a copper amalgamated electrode being used. The length of the sinus should be first ascertained and the electrode, excepting for this distance, insulated. A current strength of 10 or 15 milliamperes for fifteen minutes every other day is sufficient.

Fistula in Ano.—The above method might be tried in *fistula in ano* if a cutting operation is impracticable.

Goitre.—In the treatment of goitre either percutaneous galvanism, with or without cataphoresis, electrolysis, or both combined, may be employed. In the former method rather large electrodes should be placed, one on each side of the gland, and a constant current of 5 or more milliamperes passed for fifteen minutes every other day. If the growth is very large, a good sized electrode so made that it will closely conform to the surface of the gland should be used, while the other is placed on the back; by this method currents of 25 milliamperes or more may be used. The kathode should be made the active electrode. In using this method, cataphoresis can also be utilized, by wetting the negative electrode with Lugol's solution (iodine being electronegative, seeks the anode). If electrolysis is used, a strong, sharp, sterilized needle, which may be either smoothly insulated with shellac to within a short distance of the end or not insulated, is introduced for an inch or more into the growth; it is then connected with the negative pole, the positive being placed on an indifferent point, and a current of from 10 to 20 milliamperes passed for ten minutes. The skin may be previously anesthetized by freezing with ethyl chloride. This may be repeated twice a week if necessary, and percutaneous galvanization, as above described, can be used during the interim. Electrolysis is especially valuable in cystic goitre; in these growths the contents of the cyst should be evacuated after the operation. Excellent results, especially in small tumors, may be obtained by these methods.

Cystic Tumors.—Benign cystic growths may be destroyed by electrolysis. Two needles should be inserted, one attached to the positive, the other to the negative pole. Rockwell recommends that the former be kept stationary, while the latter is moved in various directions, so as to act upon all the inner surface of the cyst, and also to enlarge somewhat the hole made by the needle in the walls of the tumor, so as to allow free exit of the fluid or gases.

Diabetes.—Snow advises a trial of the static wave current in conjunction with appropriate medical treatment. He places an electrode of about 5 by 8 inches over the region of the pancreas, with a spark gap of from 4 to 8 inches, the administration being for thirty minutes daily.

Chisholm Williams[1] has obtained favorable results with the high frequency current, either autocondensation or autoconduction. He also quotes the results of others. The usual method employed was that of autoconduction (p. 262). De Kraft[2] reports success from the use of autocondensation, especially when the blood pressure was high. The length of treatment varied from twenty to thirty minutes and from 400 to 650 milliamperes of current being used. If the blood pressure is

[1] High Frequency Currents, p. 159.
[2] Journal of Advanced Therapeutics, February, 1910, p. 59.

low, he advises the use of a long soft effluve with a grounded metal plate on the back. He explains the beneficial results as being due to the influence of the high frequency current in regulating the circulation, increasing the oxidation of the tissues (pp. 130 and 135), and that "perhaps the improvement in the walls of the arteries, with the greater flushing of the capillaries, helps to increase the muscle juices and helps the final oxidation of the glycogen in the muscles and glands, thus nourishing the sugar hungry cells and preventing the sending out of signals to the liver cells for more sugar; thus halting the overproduction of sugar.

Obesity.—Williams also quotes several authors as having obtained excellent results by the use of the high frequency current in this annoying condition. Autoconduction was used. Vigorous daily general faradization by the Weir Mitchell method (p. 252) often gives good results.

Anemia and Chlorosis.—The high frequency current may be of service in these conditions. Snow recommends either the wave current, sparks, or the brush discharge.

RESUSCITATION BY THE ELECTRIC CURRENT OF THOSE APPARENTLY DEAD

The electric current, if obtainable, is of service in resuscitating those apparently dead from asphyxia due to any cause, *i. e.*, anesthetics, drowning, electrocution, etc. The rationale of the method consists in causing rhythmic contractions of the respiratory muscles by means of electric excitation. Any current may be employed, but which ever is used must be strong enough to cause contractions. Dr. Louise Robinovitch[1] after extensive experimentation states that any current may be used, but she prefers the current of low potential and frequent interruption (Leduc current, p. 129), with an induced current furnished by a large coil composed of wire at least $\frac{6}{10}$ mm. in diameter as second choice. The electrodes are placed one on the dorsal and the other on the lumbar region, the former measuring 25 by 30 centimeters, and the latter 12 by 25 centimeters. They should be well covered and wet with salt solution. It is important that the head be excluded from the circuit.

The dorsal electrode is made the kathode and the lumbar the anode. The minimal voltage necessary to produce good contractions should be employed. From 20 to 90 volts or from 4 to 50 milliamperes usually give good results in man. The circuit is alternately closed and opened, more frequently than the normal respiratory movements, and the voltage gradually increased, if necessary, until good respiratory and cardiac movements are obtained. Robinovitch has devised a special portable form of apparatus for this purpose. High frequency currents

[1] Journal of Advanced Therapeutics, August, 1910, p. 369.

may be applied to the back if nothing better is at hand. During the treatment the mouth should be kept open, the tongue drawn forward, and other measures appropriate for shock employed. The resuscitation of those suffering from electric shock requires special mention. It causes death principally by causing paralysis of the heart with fibrillary contractions of this organ, asphyxia is associated secondarily. An exception to this is where there is a good contact with a high tension current when respiratory failure only occurs. In most accidental cases the contact, is poor and hence cardiac involvement is present. After the victim is removed from the circuit he should be laid with his head higher than the rest of the body and artificial respiration begun. One of the usual methods, preferably by compressing the thorax by the hands on each side low down and tickling the epiglottis with the forefinger at intervals, or one of the electric methods described on page 401, is employed. Massage over the cardiac area, the injection of a dose of adrenalin, which according to Crile and Dolley is best introduced into an artery toward the heart, intravenous injections sometimes giving bad results, and the faradic current, one pole on the side of the neck and the other over the heart, may be used. Lumbar puncture may also prove of service, as the intradural pressure is usually very high. In cases where fibrillar contraction paralysis of the heart is present (shocks from a low tension current), a momentary application of a high tension current may start cardiac action if done soon. This, however, should be a last resort.[1]

[1] Spitzka, Resuscitation of Persons Shocked by Electricity, Proceedings of Medical Society of New Jersey, 1909.

SECTION VII

THE APPLICATION OF THE RÖNTGEN RAYS IN MEDICINE

CHAPTER XXVIII

NATURE AND PRODUCTION OF X-RAYS

The almost accidental discovery of the so-called "x-rays" by Professor Röntgen, of the University of Würzburg, in November, 1895, was not only a personal triumph and an advance step in science, but it has since proved a benefaction to humanity in having given to medicine and surgery a means of diagnosis and a therapeutic agent that have proved invaluable. If the reader is not familiar with the line of scientific investigations leading up to this discovery and the immediate circumstances attending it, the numerous books on the subject of Röntgen rays will serve as much better references for this information than the small portion of this chapter that could be devoted to such data. It will be necessary, however, to refer briefly to some of the physical phenomena manifest in connection with the x-ray tube in the generation of x-rays, in order to explain satisfactorily the proper use of the apparatus and the application of the rays.

To beginners and those about to engage in x-ray work, and also to the general practitioner and the specialist who refer patients for examination or treatment, a knowledge of the fundamental principles of the production of x-rays, the physical properties of the latter, the full extent of their practical use, and the possible dangers attending their application is most essential. To the physician and the surgeon, such knowledge is important, not only for the benefit of their own instruction and understanding, but also for the best interests of their patients.

While a certain amount of text-book study of the subject and a reasonable knowledge of physics are essential qualifications in the beginner in this specialty, it is actual experience alone, combined, of course, with an adequate medical education, that can render him efficient and sufficiently competent to assume the responsibilities attending the use of Röntgen rays. It may be said of nearly all books on Röntgen rays and their application that they are of little actual value

as sources of *practical* learning to the beginner, and those published many years ago, unless recently revised, are practically useless to anyone. And it may be appropriate to state here that the purpose of this section is not to teach, but to assist in the acquirement of theoretical and practical knowledge of this subject in so far as the suggestions offered may direct the reader in the proper channels of study, thought, and action.

One fact that should be clearly understood at the very beginning is that the output of energy from an x-ray tube is something that is subject to extreme variations and is very uncertain. This applies to both the quantity and the quality of the rays produced, and one of the essential qualifications in a successful operator is his ability to so understand and to so manipulate his apparatus and tube as to obtain an output of energy that is best suited to accomplish the particular kind of work to be done. Moreover, although largely dependent upon the manufacturer for the designing and construction of suitable apparatus, he must assume the responsibility in the selection of that which will be adequate and efficient for all varieties of x-ray work he is likely to be called upon to perform.

Properties of the X-rays.—It will be recalled (p. 52) that when an electric discharge is passed through a highly exhausted tube it consists almost entirely of the so-called *kathode rays,* streams of free electrons which issue from the kathode at right angles to its surface and proceed in straight lines until they impinge on some obstacle or on the walls of the tube. Their speed is enormous, being one-tenth to one-half of the velocity of light, varying with E. M. F. employed to produce them. By their impact they produce a considerable heating effect, in many cases cause fluorescence (an effect always noticeable on the walls of the tube), and effect decomposition of silver salts in a manner similar to the action of light.

In addition to the above-mentioned effects, it was discovered, in November, 1895, by Wilhelm Conrad Röntgen, of Würzburg, that the kathode stream is the cause of a new kind of invisible radiation, to which, in ignorance of its nature, he gave the name of *x-rays.* The source of these rays was traced to the walls of the tube on which the kathode rays impinged, and it was afterward found that the intensity could be much increased by concentrating the discharge (by means of a concave kathode) upon a disk of platinum or other heavy metal, which then became the source of the radiation.

The existence of these rays was discovered from their producing fluorescence on a screen coated with barium platinocyanide and also from their affecting a photographic plate. They have some of the properties of light rays. Thus, they travel in straight lines, and their velocity, which has been recently measured, seems to be the same as that of light. Their intensity falls off according to the same law—that of the inverse square of the distance. Like light rays they are not deviated by a magnetic field, which proves that they do not, like

kathode rays, consist of a stream of electrically charged particles. Different substances are more or less transparent to them, though the order of transparency is quite different from that for light. Thus, the rays penetrate aluminum, wood, paper, etc., more readily than they do glass. In general, the transparency of a substance is approximately proportional to its density, so that lead, platinum, etc. are most opaque to the rays.

This penetrating power is not constant for all rays, even from the same tube, but depends upon the circumstances of their production. The greater the speed of the kathode rays which produce them and the denser the substance on which they impinge, the more penetrating are found to be the x-rays. As this speed is determined by the applied potential, which must be greater to produce a discharge when the vacuum is higher, it follows that the greater the exhaustion or resistance, the more penetrating are the x-rays from the tube. Rays which have a high penetrating power are called "hard" rays, while those which are easily stopped are termed "soft" rays; and a tube is called "hard" or "soft," according as one or the other kind of rays predominates.

One important respect in which x-rays differ from light rays is that they cannot be reflected or refracted, but pass directly through objects of any form without the slightest deviation. It is this property, together with the varying degree of penetration through different substances, which has proved so valuable, as it permits shadows of the interior parts of the body to be projected without distortion upon the fluorescent screen or the photographic plate. On the other hand, this impossibility of reflecting or refracting the rays, prevents their concentration by mirrors, lenses, etc., as is done with light.

One of the most characteristic properties of x-rays is their power of producing ionization, *i. e.*, of breaking up the molecular structure of the substance upon which they fall and liberating ions or electrons. This ionization takes place even in the air through which the rays pass, which is thus made conducting (pp. 49 and 52). In addition to the ionizing effect, their impact produces a secondary radiation of x-rays similar to the primary rays, but of less penetrating power. These again may produce tertiary rays, and so on.

In fine, the effect of the x-rays is, therefore, seen to be a profound shaking of the molecular structure of matter, causing it to so vibrate as to emit fluorescent light, producing chemical decomposition, and even disintegrating the atoms, liberating electrons, and producing new radiations of like properties to their own.

Nature of X-rays.—At present two views prevail as to the nature of the Röntgen rays. According to the theory most generally accepted at present, known as the ether-pulse theory, they consist of disturbances in the ether set up by the sudden stoppage of the electrons in the kathode stream by their impact upon an obstacle. These disturbances travel outward from the corpuscle with the speed of light and, in fact, are of the same nature as light waves, but differ from them in being short

irregular pulses instead of continuous trains of waves of regular form, and of much briefer duration than even the most rapid light waves.

Such a pulse consists of an intense electric and magnetic field spreading outward in a spherical shell. The energy of the pulse is dependent on the original velocity of the kathode particle, and the more suddenly the particle is stopped the quicker is the pulse, and hence the thinner the shell of outward spreading radiation. As the energy is thus compressed into a thin shell, its intensity is very great. This accounts for the greater penetrating power as the speed of the kathode particles is increased, and explains one advantage of using a disk of platinum or other heavy metal to receive the impact of the discharge.

If a molecule were struck by such a shell the strong electric field would cause a considerable disturbance. The molecule might be split apart, or an electron be shaken out, thus producing the phenomenon of ionization. The sudden liberation of an electron would produce a similar effect on the ether as its sudden stopping, so that secondary x-rays would be produced.

The above theory, which was first suggested by Stokes, and developed by Thomson and others, is thus seen to offer an adequate explanation of the principal phenomena of the x-rays. An alternative theory was proposed by W. H. Bragg, in 1907, that the radiation consists, like the kathode stream, of particles projected with high velocities, but that, unlike the kathode particles, they carry no charge. They are, in this theory, neutral doublets, consisting of a negative electron and a neutralizing positive charge. Their great penetrating power is explained by this fact, as they are much less influenced than charged particles in their passage through matter by the powerful electric forces existing in the interior of molecules. Bragg has shown that the properties of x-rays may be satisfactorily explained on his theory. The matter is still under discussion, and it is not improbable that the Röntgen radiation is really complex and that disturbances of both kinds may coexist.

Apparatus for the Production of X-rays.—The two essential parts of the equipment necessary for the production of x-rays are, first, the apparatus to generate an electrical current of sufficiently high potential to produce the kathode discharge, and secondly, the vacuum tube in which the discharge takes place. The electrical apparatus may be either a static machine, an induction coil, or a transformer. These will be considered in turn.

I. THE STATIC MACHINE

This apparatus is described elsewhere in this book (p. 36). At the present day there is not much to be said in its favor in connection with x-ray work. From a practical standpoint, it possesses two advantages. In the first place, it is the only resort in a section in which there is no available source of electricity for the operation of a coil, such as an

electric lighting circuit or plant. Secondly, if the static discharge itself is to be used for other therapeutic purposes and the operator cannot be burdened with the two forms of apparatus, the static machine is, of course, the one best adapted to the requirements. While the energy furnished is sufficient for practically all therapeutic and fluoroscopic work and for ordinary radiographic work, its maximum output is far below that of a modern induction coil, and rapid radiographic exposures, which are often essential and always desirable, are out of the question. Rapidity is essential in radiography of the thorax and the gastro-intestinal tract. Rapid exposures undoubtedly yield better results in all instances, although speed is not essential in, perhaps, the majority of examinations, such as ordinary fractures. Prolonged and repeated examinations of such regions as the abdomen and hip are attended with the risk of an *x*-ray dermatitis, and in the case of the head there is the additional danger of injury to the hair follicles and loss of the hair.

It is now possible with modern equipment to make a radiograph of any part of the body in a second, and, in fact, the best pictures of the chest are made in a small fraction of a second. Therefore, the use of equipment that requires several minutes to make a radiograph of any part of the body is not justifiable except in emergencies such as when portable apparatus must be employed.

The static machine requires considerable care, especially in a moist atmosphere, and those of sufficient size and capacity for most radiographic work require a motor or small engine for their operation. Although manufacturers are now producing static machines capable of delivering a comparatively heavy output of energy, still, even aside from the relative increase in bulk and the trouble and energy required to run them, these machines have failed to keep pace with the improved types of induction apparatus.

II. THE INDUCTION COIL

One essential difference between this apparatus and the preceding one is that an electric current is always necessary for operating the induction coil. The term "coil" as ordinarily employed in connection with *x*-ray equipment includes the following essential parts: The coil proper, the interrupter, and condenser.

The Coil Proper.—The principles of induction and of the construction of the induction coil are discussed in another chapter, and should further details on the subject be desired, they can be readily found in any of the standard works on electricity. The discovery of *x*-rays and their subsequent wide field of usefulness, together with the perfection and application of wireless telegraphy, have called for an unusual development of an apparatus which formerly had little practical use.

In the earlier days of *x*-ray work it was often the custom to compare the capacities of coils roughly by the lengths of the sparks they were

able to produce between their terminals. Spark length, as has been explained, is a crude index of potential. While a certain amount of potential or voltage is necessary in any x-ray coil in order to overcome the resistance of the tube, there has been little change in the maximum potential required during the progress in the development of the x-ray tube. There has, however, been a constantly increasing demand for greater amperage in coils to meet the increasing capacity of tubes, so that attention has been directed mainly in later years to an increase in the amperage output of induction apparatus. This has tended to the construction of coils capable of producing comparatively short but "fat" sparks rather than long thin ones. In fact, many of the most powerful coils of the present day are not intended to produce spark discharges much if any longer than 12 inches, or, at least, their terminals are not placed farther apart than this.

The design of a coil is determined by the available source of the primary current. This may be either a storage battery, an ordinary lighting circuit, or a special dynamo. The most convenient source of current is the usual lighting circuit of 110 or 220 volts, direct current, and large coils are usually designed for this voltage. Where the lighting circuit is alternating, it must usually be changed into a direct current by a rectifier or motor-generator (p. 87). It is important that the source of supply should be adequate for the maximum demands of the coil, and that a proper rheostat be supplied to control the current. Switches and fuses for protection must also be added.

Portable coils are usually designed for lower voltage—20 volts or less—and are operated by a storage battery. In an emergency the battery of an electric automobile may be used.

The prospective purchaser of an induction coil can find an almost endless variety of equipments from which to choose. All of them embody the same principle of induction, but there is a vast difference in the efficiency of many coil equipments, even aside from the acknowledged differences in their capacities. Experience is always the best guide in the selection of an outfit, but even an experienced x-ray specialist would display lack of discretion were he to purchase expensive apparatus without having sufficient personal knowledge of its actual merits to feel assured that it will meet all his requirements. Although most manufacturers and dealers are to be regarded as thoroughly honest and reliable, the inexperienced beginner in x-ray work should remember that their greatest aim is to sell their apparatus. As a rule, therefore, he will run a better chance of obtaining satisfaction if he will permit himself to be guided more by the advice of an experienced Röntgenologist in selecting his apparatus than by the praises proclaimed by expert salesmen.

The Interrupter.—A very important adjunct to a coil is an efficient interrupter. The action of the interrupter and the principal types have been described in an earlier chapter. For convenience, further details as to their construction and operation are given here.

The Mechanical Spring Interrupter.—The simpler forms of this type have already been described. Fig. 338 represents a more complicated form acting on the same principle. The magnet of this interrupter (which is separate from the coil) is not excited by the whole primary current, but is connected in a shunt circuit to the latter, and, being of high resistance, uses but a small fraction of the primary current. In explaining its operation we may assume that the direction of the primary current is upward through the metal post *D*, the brass screw *C*, and the interrupting spring *A*, thence through the primary of the coil. The interruptions in the primary circuit are caused by the separation of the platinum contact points at *E*, one of which is on the end of the screw *C*, and the other at the top of the spring *A*, and projecting through an opening in the spring *B*. The interrupter is operated on a separate shunt circuit, the current passing up through the metal

Fig. 338

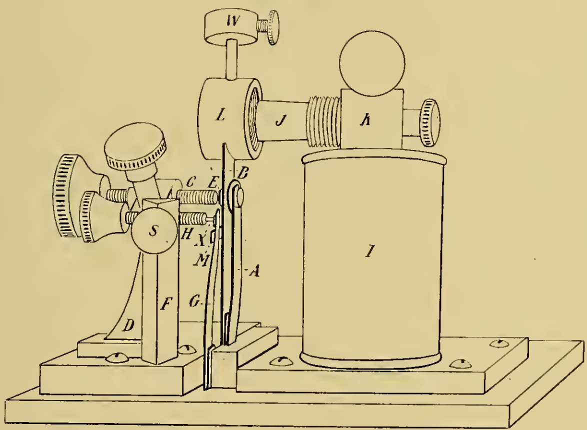


Diagram of the "Röntgen self-starting mechanical interrupter."

post *F*, through the screw *H*, the spring *G*, and then through the winding of the magnet spool *I*. The interruptions in this circuit are made by the separation of the platinum contact points at *X*, one of which is at the end of the screw *H*, and the other near the top of the spring *G*. These contacts must be properly adjusted before starting the interrupter in order to make it work.

When the interrupter switch is closed, the magnet spool *I* magnetizes the core *K* and the pole piece *J*. The resulting pull on the armature *L*, and its spring *B*, drags back the spring *A*, and breaks the primary circuit at *E*, if the contacts there are not already separated. At the same time, a metal arm, *M*, attached to the spring *B*, pulls back the spring *G* and breaks the interrupter circuit at *X*. The pole piece *J*, being thereby demagnetized, releases the armature and its spring (*LB*), which fly back and allow the contacts to be made again at *E*

and X. These contacts are made before the spring B has reached the farthest point in its swing, so that on its return it strikes the springs A and G at a period when it has gained practically its maximum velocity and produces an extremely quick break, which may be made even more abrupt if the amplitude of vibration be increased by the attachment of the weight W. This weight also serves to adjust the frequency of interruption, which is slower as W is increased or moved farther up toward the top of the spring.

Among the advantages of such an instrument, aside from the small amount of current it requires for its own operation, are the narrow gap in the magnet field between the pole piece and the armature, whereby the pull on the armature is of such strength that the instrument is always self-starting when once adjusted; the simplicity of the adjustment of the contacts; the slight amount of attention the instrument requires; the comparatively wide variations in frequency and output of energy possible; and the slight amount of heat generated. An occasional filing of the contacts is practically the only attention required, and with care these do not have to be renewed often. To make the first adjustment, the interrupter circuit is first closed and the screw H is turned until interruptions begin, and it is then made tight by the set screw S. All that remains to be done is to bring the contact points at E into close or actual contact.

Mercury Interrupters.—In this type of metal contact interrupters one of the metal contacts is mercury. All the various forms of such instruments are modifications of one or the other of two general types, namely, *dip* or *plunger* and *turbine* or *jet* interrupters. All of them must be operated by a separate motor, which renders the equipment still more complicated. The special advantages that can be claimed for these instruments are the high rate of interruption possible, the relatively perfect metallic contact made by the mercury, and the so-claimed lessened tendency to arcing immediately after the break, owing to the high electrical resistance of the mercury vapor which is produced at the point of contact.

On the other hand, there are limitations to the use of this form of interrupter. Principal among these is that the current-carrying capacity is limited. As the present tendency is to use heavier primary currents, it is probable that mercury interrupters will become less and less used. Another objection to their use is that oxidation of the mercury fouls the contacts, necessitating frequent cleaning. The oxidation is lessened but not entirely prevented by covering the mercury surface with a layer of oil or alcohol.

In interrupters of the *dip* or *plunger* type, the motor operates a platinum-tipped conducting rod in such a manner that the circuit is closed and opened by the alternate dip into the mercury and immediate withdrawal therefrom of the platinum tip. Fig. 339 is a diagram illustrating the principles of this type of interrupter. The electric motor A, through the medium of the crank B, attached

eccentrically to the motor shaft C, raises and lowers the plunger D, terminating below in a platinum tip which dips below the surface of the mercury M, in the vessel E, when at the lowest point of its drop.

The plunger should strike the surface perpendicularly so as to create the least possible disturbance in the mercury. The rate of interruption is regulated by the speed of the motor, which in its turn is controlled by a rheostat. An average rate is in the neighborhood of 1000 interruptions per minute. Alterations in the relative periods of the make and break in the interrupter may be accomplished through raising or lowering the mercury cup E, by means of the screw F. Raising it prolongs the make period, but the break is more sudden, because it occurs at a time when the plunger approaches its maximum speed in its ascent. This principle is similar to the one involved in the mechanical spring interrupter.

FIG. 339

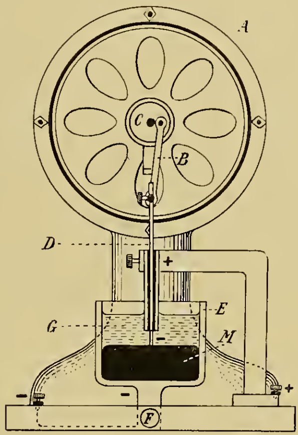


Diagram representing the principles of the dip or plunger type of mercury interrupters.

Johnston's Interrupter.—This instrument, devised in 1905, is of the plunger type, and is worthy of mention for the reasons of its comparatively high amperage capacity and of the fact that certain principles in its construction tend to overcome the most troublesome features common to all mercury interrupters. The only visible parts are a rectangular iron box surmounted by a small motor which operates the essential mechanism contained in the box. The metal top is insulated from the remainder of the box, and when screwed down renders the latter air-tight. A rough iron inclined sluiceway runs from near the top of one end of the interior of the box down to a mercury chamber at the bottom of the other end. The plunger is a blade attached perpendicularly to the lower extremity of an inclined shaft, which is rotated by a belt running from a pulley at its upper extremity outside the box to another pulley on the shaft of the motor. The latter is under the control of a separate speed adjustment. At the lowest point

in its circle of rotation the tip of the blade dips into the pool of mercury at the foot of the inclined sluiceway, and at each dip not only does it make and break the circuit, but in addition the blade throws some of the mercury up to the top of the sluiceway. In running down the latter to regain the pool, the mercury descends slowly in shallow zigzag grooves in the incline, and in so doing a large part of the dirt and oxide it carries are left behind adhering to the roughened iron surface. This part of the mechanism is based upon the principle involved in the recovery of gold in placer mining. In preparing the instrument for use, the mercury is introduced into the box through a pet cock, and before starting, a few drops of wood alcohol are added. The arcing attending the first dip causes a slight explosion of the alcohol, which uses up all of the oxygen, so that further oxidation is impossible. There is said to be comparatively little arcing in this instrument. It has a capacity for 40 or 50 ampères, or even more. Its construction being simple, the instrument is easily cleaned, but this does not have to be done very often.

Turbine or Jet Interrupters.—In all instruments of this type a jet of mercury is one of the metal contacts. The one essential point of difference in their construction depends upon whether the mercury jet escapes from a stationary orifice and strikes the contact segments of a rotating metal conductor, or the reverse. In all such instruments the mercury drops into a reservoir, whence it is forced up to and out through the one or more orifices by some turbine or other pumping device, which together with the rotating conductor is operated by the motor. In addition to the same objectionable features mentioned in connection with the preceding type, all jet or turbine interrupters have a still more limited capacity.

Electrolytic Interrupters.—As previously stated (p. 96), these are of two types, of which the more usual form is the Wehnelt interrupter. At the present time this type of interrupter is more generally employed with the coil for radiographic work than any other, although recent improvements in the mercury interrupters have brought them again into extensive use. The Wehnelt instrument is much simpler, however, and requires but little attention and care in comparison. In addition to these advantages, not only is it capable of an unusually high rate and wide range in frequency of interruptions, but still more important is the fact that it has a very high amperage capacity, and will interrupt currents of any amperage that may be desired in an x-ray coil, and without danger or unreasonable wear. These advantages have made it the instrument of choice for radiographic work, but it is perhaps not so generally satisfactory for therapeutic work when a direct current is available. Still another advantage is the fact that it works to better advantage than any other type of interrupter in connection with variable inductance in the primary.

The fundamental principles of the operation of the Wehnelt interrupter have been already discussed. There are four important factors to be considered in its action, namely, the rate of interruption, the

strength of the current, the extent of surface of the anode exposed in the solution, and the rate of evolution of gas at the anode. All of these factors are more or less intimately related.

The rate of the interruptions, which may vary from one hundred to one thousand or more per minute, depends primarily upon the rate of evolution of gas over the anode surface, which in its turn depends upon the strength of the primary current, and, secondarily, upon the anode surface exposed. It is increased by lessening the anode surface or by increasing the current, the latter increasing the rate of evolution of gas, while the former allows a more rapid escape of the gas in bubbles. It is also influenced to some extent by variations in primary inductance.

The rate of interruption in itself is of far less importance in connection with the output of secondary discharge than is the *energy* each interruption represents and which largely determines the energy of each secondary impulse. If this be the only type of interrupter employed, the two extreme limitations in its range are, as a rule, brought into use in the general run of *x*-ray work. A heavy secondary discharge is required for radiographic examinations, and in many instances this must be the maximum output capacity of the coil, and under such circumstances, the capacity of the interrupter should not be too much of a limiting factor, but should be proportionate to that of the coil. The high primary current required for a heavy secondary discharge will not be properly conducted or interrupted by the electrolytic interrupter unless an adequate extent of anode surface be exposed. Although lessening the rate of interruption, an increase in the anode surface usually requires a larger primary current, so that the increased energy in each secondary impulse more than counterbalances what is lost through lessened frequency.

Therapeutic applications require a much lighter secondary discharge, and very often the lightest that can be obtained from the coil through the use of the electrolytic interrupter. Under such circumstances the primary current must be much lower than in radiographic exposures, but as a weak current will not be interrupted unless the anode surface is comparatively small, the amount of platinum exposed must also be reduced. Although this increases the frequency of interruption considerably, the effect is more than counterbalanced by the decrease in the amount of energy represented in each impulse.

If a single interrupter be used for both radiographic and therapeutic work, the anode will have to be readjusted constantly when treatments are continually alternating with examinations, and this becomes a rather troublesome procedure. This difficulty may be largely obviated by using an interrupter provided with two or more anodes. Even with two anodes, one of them may be used in connection with all therapeutic applications, and the second, with a much larger surface of platinum exposed, may be reserved for radiographic exposures. Coils with which such instruments are used are provided with a multiple contact switch, by means of which any one of the anodes desired may be placed in

series with the primary. With a direct current, it is more economical and often more satisfactory to use a mechanical spring interrupter for therapeutic work, and the electrolytic for radiographic work only.

The adjustment of the anode is made more readily and more exactly through the assistance of an ammeter in the primary circuit. After learning by experience the exact value of the current at which interruptions should begin when the anode is properly adjusted for each condition or kind of work, all that the operator has to do, in order to make the proper adjustment for any particular need, is to adjust the platinum point until interruptions just begin with the appropriate current passing through the primary circuit as indicated by the ammeter. Without this instrument, the appropriate adjustment can be only approximately made, as it must be based upon the interruptions beginning when the rheostat switch is at a certain definite point for therapeutic applications and at another for radiographic work. The important object always in view is to obtain the maximum secondary discharge, as determined by the milliammeter, with the minimum primary amperage.

There are numerous other important points to be considered in connection with the Wehnelt interrupter and its operation and care. The electrolyte should be of a certain definite strength, and a solution of from 15 to 20 per cent. sulphuric acid by volume will give the best results. Beyond these limits, the resistance of the liquid lessens the efficiency of the instrument. The resistance of the electrolyte, the chemical changes upon which the interruptions depend, and a certain amount of arcing at the anode are productive of considerable heat, and a high temperature in the electrolyte will lessen the efficiency of the instrument. This difficulty is best avoided by the use of a vessel of sufficient size to hold such a volume of solution as will heat up slowly.

The sulphuric acid solution gradually becomes weakened through decomposition by the electrolytic action, and should be entirely renewed occasionally. Moreover, there is likely to be a gradual loss in volume, first, from evaporation, which is favored by the heat generated, and secondly, through a fine spray which is thrown off during vigorous bubbling attending the passage of heavy primary currents. The level of the liquid should be carefully watched, and fresh solution added in case of any appreciable loss in volume. The spray is destructive to objects within range. These difficulties may be partially overcome by covering the surface of the solution with a thin layer of ordinary machine oil. This may give rise to a disagreeable odor unless the level of the liquid is kept well above the platinum electrode. The vessel should be enclosed, preferably by a wooden hood or box, the top of which is represented in the diagram (Fig. 71). By thickly coating the box inside and out with paraffin, the destruction of the wood by the acid spray will be greatly retarded. The floor or table upon which the interrupter stands may be protected by placing the whole apparatus in a large glass tray. As the gases generated by the interrupter are very explosive in the proportions in which they are evolved, there should be numerous

openings in the sides of the box to permit free ventilation. For the same reason the interrupter should not be shut up in a small closet when in use. Explosions are certain to occur if the level of the solution is not kept well above the platinum electrode. If the platinum tip is not well covered, a gas bubble may form a direct communication between the flash and the air and gases above the surface of the solution. Slight explosions frequently take place in the liquid itself, due to the ignition of large bubbles of the two gases by the arcing at the positive electrode. The electrolytic interrupter is, under all circumstances, a very noisy instrument, but this objection, as well as that of any disagreeable odor, may be overcome by keeping it in an adjoining room.

It may be necessary to expose more of the anode from time to time, as the platinum tip may become disintegrated by the electrolytic action and arcing. Here, again, an ammeter in the primary circuit will be found of great service in indicating the necessity for such readjustment, as well as showing the amount needed. With ordinary care the erosion of platinum is slow on a direct current, but is much more rapid on an alternating current. Iridioplatinum tips are far more durable, and more economical in the long run. After prolonged use of the interrupter, the lead electrode becomes coated over with an insoluble salt, due to the action of the acid and the electrolytic reaction, and this may lessen the efficiency of the instrument. The entire interrupter had best, therefore, be given a thorough cleansing at least as often as it is necessary to renew the electrolyte.

Slight variations in voltage, such as a drop of a few volts, do not influence the operation of this interrupter to any great extent, whereas the mechanical spring interrupter is very susceptible to slight changes in the primary potential. The electrolytic instrument is not adapted to low voltages such as those from storage cells used in connection with portable coils.

When the direction of the current is reversed, so that the platinum point is made the negative pole, much greater resistance is offered to the passage of the current, and the interruptions are very irregular and infrequent. The interrupter can, therefore, be used as a means of determining the polarity of the current. The failure of the instrument to interrupt properly shows that the polarity is reversed, and either the attachment of the wires to the interrupter must be changed or the direction of the current reversed by means of the reversing switch. The passage of the current in the wrong direction for any great length of time causes rapid destruction of the platinum tip.

On account of this action, it is possible to use the Wehnelt interrupter in an alternating current circuit, as the current passes practically in one direction only. The interrupter, in fact, acts as a rectifier (p. 87), one phase of the current being suppressed. The suppression is not complete, however, and, moreover, the platinum terminal is rapidly wasted, so that it is much better, when only an alternating current is available, to include a rectifier in the circuit.

The interrupter of the Caldwell type (Fig. 73, p. 97) does not depend upon electrolysis for its action, and, therefore, will work equally well in either direction of the current. It will, therefore, operate on an alternating circuit, but as an alternating secondary discharge would then be produced, it is necessary in x-ray work to use a rectifier in series with the interrupter. Except for this difference, the action of the Caldwell interrupter is similar to that of the other type, and many of the above suggestions will apply to either form. It permits a wide range of frequency, and is said to be less susceptible to variations of voltage and temperature than the Wehnelt instrument.

The Condenser.—The theory of the condenser and the construction of its various forms will be found on page 32, and the action of the condenser in modifying the induction coil discharge is discussed on page 94. A condenser is not used with the electrolytic interrupter, as this form of break has a property somewhat equivalent to capacity; but with a mechanical interrupter the condenser forms a very important adjunct. For any large coil the condenser should be made in sections, as in Fig. 10 (p. 33), so that its capacity may be regulated to suit the conditions of the circuit.

III. THE TRANSFORMER

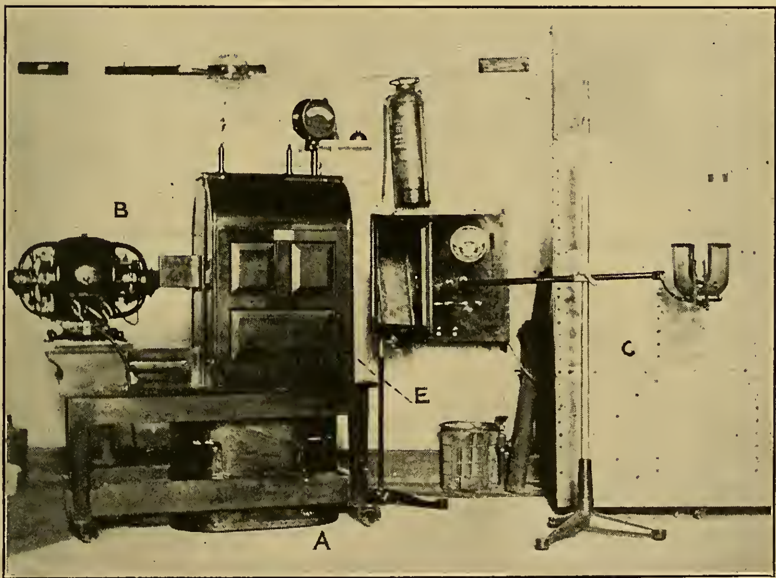
It will have been noted in the foregoing pages that certain difficulties are always to be encountered in the successful operation of the two types of x-ray apparatus so far described. The one important drawback in connection with the static machine is its very limited capacity, but in the use of the induction coil we find not only this limitation, though to a less extent, but, in addition, certain troublesome features peculiar to it, and some of which have become decided obstacles to perfection in x-ray work. There are at least four decidedly objectionable features in connection with the coil. The most troublesome of all, perhaps, is the *interrupter*, and the demand for increased capacity has tended to increase both the troubles ordinarily encountered and the complexity in construction. Secondly, a most undesirable factor, and perhaps the greatest obstacle to be overcome in the proper manipulation of a coil and the tube, is the *inverse discharge*, the satisfactory elimination of which always means a complete loss of the amount of energy it represents. Thirdly, the necessary use of alternating currents has always been more or less of a disadvantage and an added expense. Fourthly, limitations in the capacity of coils has at last become a decided drawback. While at first the capacity of tubes limited that of coils, the state of perfection reached in the construction of tubes at the present day has made the capacity of the coil the limiting factor in rapid radiographic exposures.

With a view of overcoming all these difficulties, Mr. Snook, of Philadelphia, recently (1907) devised an apparatus in which a high potential *transformer* (p. 103) is substituted for the induction coil. Although the

principle of operation is the same, an enormous increase of effect is obtained because of the closed magnetic circuit of the transformer. An alternating current is sent through the primary of the transformer, thus doing away with the troublesome interrupter, and an alternating high potential current is accordingly induced in the secondary. The essential feature of Mr. Snook's apparatus is the rotating commutator or rectifier, which converts this alternating secondary current into a unidirectional current. This device is of exactly the principle of the commutator on the electric motor or dynamo (p. 81), but must be of special construction to handle the high potential current.

This apparatus has effected such a decided advance in radiographic work and in the scope of x-ray diagnosis, that it merits a brief discussion. The general appearance of the apparatus is shown in Fig. 340. It consists of the following essential parts:

Fig. 340



1. A high potential *transformer, A,* enclosed in a metal case and immersed in oil for more complete insulation. This transforms a primary alternating current of about 100 volts up to approximately 100,000 volts.

2. An *alternating current generator, B,* to supply the primary alternating current. This, if the power is supplied from a direct current system, is a *motor-generator* (p. 87), inverted so that the direct current side is connected to the mains and used as the motor. When the power supply is alternating, an alternating current dynamo is substi-

27

tuted for the motor-generator. This must be driven by a separate alternating current motor which is excited by the line current.

3. A *rectifier* or *commutator,* consisting of rotating contact arms which commutate the secondary current at the proper time. This is enclosed in the hood E, and must be highly insulated to prevent cross-sparking. In order to secure exact synchronism of the commutation with the reversals of the secondary current, the commutator is directly attached to the shaft of the motor generator and revolves with this.

All controlling switches and the rheostat are mounted on a portable switch table or stand, from which long connecting cables extend to the machine, thus permitting of its operation from behind a screen, a lead booth (C, Fig. 340), or even from an adjoining room, The *rheostat* is in series with the *primary* and not with the line circuit.

The three special features, and likewise distinct advantages of this apparatus are:

1. The absence of an *interrupter.* In this apparatus the alternating primary current delivered by the motor generator serves the purpose.

2. The *elimination of the "inverse"* by the rectifying device not only removes one of the heretofore most serious obstacles in x-ray work, but does it in such a way as to *utilize* and not suppress a large amount of energy that must of necessity be wasted in the proper manipulation of the coil. Valve tubes and series spark gaps are thus rendered unnecessary, and their troublesome and annoying features obviated.

3. A great increase over the coil in output capacity has served to materially lessen the time of radiographic exposures. A most striking and valuable example of this is in examinations of the chest, which can now be made instantaneously, or in less than one-quarter to one-half a second. This insures far better detail through the elimination of all motion occasioned by unconscious or imperceptible slight muscular movements of the body or in respiration, as well as the blurring effects due to pulsation of the heart, which may be radiographed practically at rest. Moreover, the great output capacity of this apparatus can be readily controlled through wide ranges, from less than one milliampère up to an amount that no tube can stand for more than one or a very few seconds.

Considering its output of energy, this apparatus can be operated on far less current than the coil. It is well adapted to use on alternating currents, which is not the case with coils, and practically the only disadvantage in this connection is the necessity of an additional motor.

As the maximum output of this machine is sufficient to destroy human life, great care should be observed in its operation for radiographic work. It is a wise plan to stop the motor in every instance when it becomes necessary for the operator or anyone else to go near the tube or wires leading thereto for any purpose whatsoever.

The questions of limited output capacity and inverse being disposed of, there still remains unsolved the important problem of an apparatus able to meet these same requirements, but in addition capable of deliver-

ing a *continuous* high potential discharge like that of the static machine. It is not unreasonable to believe that this will likewise be attained in the near future.

THE X-RAY TUBE

Aside from experience and medical knowledge, the direct qualifications necessary for the operation of a tube in such a manner that the quality and intensity of its output will be those best adapted to the accomplishment of the work required; to operate it to the best advantage under the existing conditions; and with the avoidance of all unnecessary risks, are: (1) The ability to manipulate properly the apparatus supplying the electrical energy to the tube. (2) A full understanding of both the manner in which this electrical energy is transformed into x-rays and the physical principles involved therein.

Fig. 341

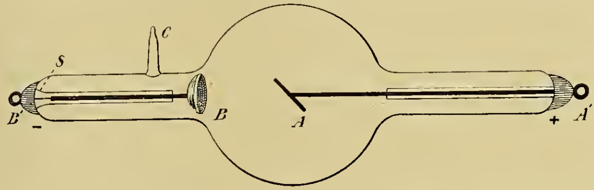


Diagram illustrating the essential principles in the simplest type of an x-ray tube.

Fig. 341 illustrates diagrammatically the simplest form of the modern type of tube, showing such parts only as are absolutely essential in every x-ray tube, and lacking in all of the modern devices for overcoming the difficulties encountered in tubes of early construction, which were, in fact, far more crude than one such as the diagram represents. Unfortunately, glass is the only material that can be used in their construction, hence it is essential that the very best quality be used, for not only must the bulb be blown exceedingly thin, that of the anterior portion being usually about the thickness of heavy note paper, in order to minimize the absorption of soft rays; but it must withstand the severe strains imposed by very sudden and unequally distributed extreme changes in temperature, as well as the external pressure of the atmosphere, which is practically fifteen pounds upon every square inch of surface.

Fragile tubes are liable to collapse at any time, and for this reason are dangerous to both patient and operator. The special danger to the latter is injury to the eyes from flying fragments of glass. Moreover, such tubes are likely to crack as the result of sudden unequal expansion or contraction at the points where the glass sustains the greatest amount of heating. The glass of at least those portions through which the rays must pass must, of course, be free from ingredients that will readily absorb x-rays, such as lead especially.

The two essential metal terminals within the tube are the *anode* or positive pole, A, and the *kathode* or negative pole, B. The former is usually placed at or near the centre of the bulb in order to serve the additional purpose of a target for the bombardment of the kathode stream, and it should, therefore, be placed at the focal point of the latter. The anode and kathode disks are mounted at the ends of metal conducting rods, which in turn should be adequately and firmly supported in stout glass sleeves or otherwise. Each disk and its conductor is connected with its respective outside terminal, A' and B', by a piece of platinum wire fused into the glass. The anode and kathode extremities of the tube always project several inches beyond the bulb, in order that they may serve the purpose of supports by clamps, and also to guard against puncture of the thin glass of the bulb by sparks. When, as is very frequently the case, the internal resistance of the tube is greater than an air gap the width of the main bulb, the discharge may pass around the outside in the form of a spark in preference to passing between the terminals inside. Such a spark might puncture the glass bulb, but this is less likely to occur if the external terminals, A' and B', are sufficiently far apart.

The *kathode* disk is invariably made of aluminum, in the first place for the reason that this metal is not so readily disintegrated as many others; and secondly, because of its lightness, which is important for several reasons. It should be placed just outside the bulb, but not *too far* out, for the same reason that its edges should not come too close to the glass, namely, that the glass is apt to become excessively heated and to crack at this point, due to the impact of too many negative corpuscles. If the disk is made too thin the life and the efficiency of the tube will be considerably lessened, but, on the other hand, it should not be unnecessarily bulky. Before purchasing a tube it is well to see that the glass sleeve supporting the kathode and its conducting rod is solidly attached at its end, S, as otherwise it is apt to crack at this point and allow the disk to drop sufficiently to either change the focal point on the target, or project the kathode stream partly or entirely underneath, so that it will strike the glass behind the target and melt a hole through instantly. Such practical points as these, and many more that follow, it is well for every operator, and especially the inexperienced ones, to bear in mind, in order to lessen the all too frequent chances of purchasing inferior or practically worthless tubes.

In all modern types of tubes except a few of special design the *anode* is made to serve the purpose of the *target* as well, and it is so constructed and placed as to present a smooth flat surface at an angle of about forty degrees to the kathode stream. It must, of course, be so placed as to receive the impact of the kathode stream at the focal point of the latter, which is a little distance beyond the centre of curvature of the concave kathode, owing to the mutually repellent forces of the corpuscles. In fact, were it not for their tremendous velocity, the corpuscles would diverge rather than converge to a focus. The exposed surface of

the target must be a disk of metal that is capable of resisting the destructive effect of the bombardment. Extreme hardness and a high fusing point are the essential qualities of such a metal, and in the simpler and the less expensive types of tubes, such as the one represented in Fig. 341, the target is simply a disk of platinum, which is, perhaps, the cheapest of all the metals that can be used for the purpose. More recently, however, it has become necessary to employ metals or alloys of still greater hardness or with still higher fusing points, such as iridio-platinum, iridium, and tantalum.

Exhaustion.—The exhaustion of *x*-ray tubes requires the prolonged operation of the mercury pump for several hours in order to obtain the high degree of vacuum needed, but this is not such a simple process as many suppose, as much more than mere pumping is necessary to render a tube capable of fulfilling even the ordinary requirements of the present day. The pump is attached to the branch tube *C*, the end of which is heated and sealed when the exhaustion is completed. The removal of a certain amount of occluded gases from the metal electrodes is a very important part of the process. A certain amount of gas is occluded by all of the metal parts within the tube, and while this is almost insignificant actually, it is usually more, nevertheless, than the amount of free gas in the tube, and if allowed to remain would be sufficient to render the vacuum too low if driven out by the heat generated during vigorous excitation. Simple exhaustion will not drive out this occluded gas, but after a moderately high vacuum has been obtained, either the target at least should be heated by excitation or the entire tube should be heated to several hundred degrees in an oven, and the operation of exhaustion continued in this way until the metals have been deprived of the *excess*, but not all, of their occluded gases.

Excitation of a tube by a heavy charge for too long a period while the target is very hot is apt to result in pitting or even puncture of the latter at the focal point, especially if the focus is sharp. On the other hand, the constant bombardment by the kathode stream under moderate excitation and without excessive heating causes a gradual roughening of the surface of the focal point, due to the detachment of small molecular particles of metal which are thrown off with violence and embedded in the glass opposite. This molecular deposit of platinum produces a purplish discoloration of the glass of the anterior hemisphere, which gradually becomes darker with the prolonged use of the tube. The other metals are also deposited more or less in the same manner, especially if inverse discharge is permitted to pass through constantly. Such deposits however, are more apt to produce a brownish discoloration, and in other parts of the tube. Before the days of the vacuum regulator the platinum deposit was regarded as a disadvantage, because in addition to its possible obstruction to the rays it was the most important factor in rendering a tube too hard for use. For much the same reason this discoloration of the anterior hemisphere is now regarded as an advantage, it being the important factor in the process of "seasoning," which

will be referred to later. A platinum deposit is a disadvantage so far as soft rays and soft tubes are concerned, but not so much for the reason of any possible obstruction it may offer to soft rays as for its tendency to harden the tube and increase penetration. Vacuum regulators have overcome all important disadvantages in this connection, and the operator must depend mainly upon new tubes for superficial therapeutic work. The real value of the platinum deposit lies in its property of readily absorbing or occluding gas and of acting as a permanent resorvoir for any excess of gas evolved through either excessive heating of the metal electrodes, should they hold too much occluded gas, or too vigorous action of the regulator. It acts as a *permanent* reservoir because it holds this gas in a portion of the tube which is not apt to be heated sufficiently for it to be readily driven off again. That the platinum particles are *embedded* in the glass is proved by the fact that in the process of "washing" out blackened tubes it is necessary to dissolve off a thin film of the glass with hydrofluoric acid before the nitrohydrochloric acid can be made to dissolve the platinum and remove it from the glass. Although any black tube can be cleaned in this way, it is rarely as efficient as before, and the expense of the process and the risk of breakage make the operation hardly worth while.

Vacuum Regulation.—The tendency of all tubes to harden with prolonged use was a serious obstacle to the early *x*-ray workers, because, in the first place, conditions then existing tended to harden their tubes more rapidly, and secondly, there were no adequate means of lowering the vacuum after it became too high. In fact, the only means of prolonging a tube's usefulness under such circumstances was to drive out some of the occluded gas by prolonged baking of the tube in an oven. This process had to be repeated more and more frequently until finally the tube became useless through permanent occlusion of all the gas. Among the first and probably the most important advances in tube construction was the application of certain devices for lowering the vacuum by the introduction into the tube of a *new supply* of gas. One of the first of these devices, and, in fact, used by Crookes in his later experiments, consisted of a small auxiliary bulb or chamber communicating with the interior of the tube somewhat like *C*, Fig. 341, and containing some sodium or potassium hydroxide. Upon the application of the heat of an alcohol flame to this bulb, some of the water of crystallization was driven off from the contained chemical, and the aqueous vapor lowered the vacuum temporarily, but was reabsorbed by the crystals when they became cool.

Subsequently two different types of vacuum regulators came into general use, and their principles are still embodied in the tubes of the present day. The *osmosis* type is diagrammatically shown in connection with a Gundelach tube (Fig. 342), but it has been used in many other types of tubes. The essential parts of this regulator are a small, narrow, and very thin platinum tube, *D′*, closed at its outer extremity, but with its cavity communicating at the inner end with the interior of the *x*-ray

tube. The platinum tube D' is fused into the projecting glass joint H. When heated to redness in an alcohol flame, the thin platinum becomes sufficiently porous to take up gas, probably aqueous vapor from the flame mainly, and which is, in turn, forced through the thin metal by atmospheric pressure and lowers the vacuum. This cannot take place when the tube is cool, however. The operation, which requires but a few seconds, should be done with caution in order that too much gas may not be forced into the tube. The main objections to this type of regulator are (1) its inconvenience as compared with the easy manipulation of automatic regulators; (2) the difficulty in controlling the proper amount of regulation.

Automatic regulation is the easiest, most satisfactory, and most exact method. Practically all such regulators have embodied the principle of Thompson's, which was a modification of the one devised by Crookes and just described. The essential difference between these two early regulating devices was that in Thompson's a platinum wire was

Fig. 342

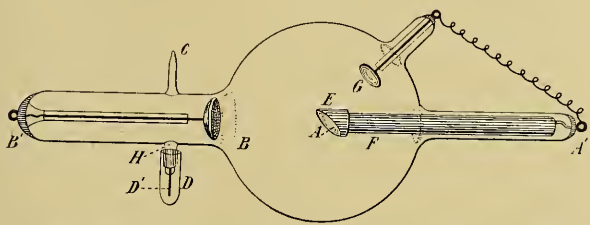


Diagram illustrating the principles of the Gundelach tube and the osmosis type of regulator.

fused through the glass of an auxiliary bulb similar to Crookes', terminating inside as an electrode and outside as a terminal to which the negative wire could be attached or brought in close contact by means of a conductor on an insulated handle, so that part of the current could be diverted through the auxiliary bulb, producing sparks through the salt crystals. The heat thereby produced was sufficient to liberate the aqueous vapor. The additional principle of the *automatic* regulator is some means of diverting the current through the auxiliary regulating bulb and of controlling the degree of vacuum or the resistance of the tube automatically. The first satisfactory application of automatic regulation was in the Queen self-regulating tube (Fig. 343) devised by Mr. Sayen. The following explanation of its construction and mechanism is abstracted in part from a catalogue description.

The auxiliary regulating bulb D, which has no communication with the interior of the tube proper, is exhausted to only a comparatively low vacuum, while the exhaustion of the tube itself (through C) is carried to either the proper degree for an x-ray tube or even higher than is usually necessary for its operation. Within the bulb D is a second smaller one, X, communicating through E with the interior of the tube,

but not with *D*. Its inner surface is coated with a salt of potassium, which when heated gives off hydrogen and oxygen, which pass through *E* into the bulb and lower the vacuum. These gases, especially the oxygen, reunite with the potassium salt as it becomes cool. The large bulb *D* is in principle a small Crookes tube, with the anode *M′* at one end, and at the other the kathode *H*, opposite which is a small platinum antikathode or target, *K*, fused into the small bulb *X*, both of which are bombarded by the kathode stream when a charge passes through the regulator, and the heat thereby evolved drives out the gases mentioned from the chemical. The kathode *H* connects with the swivel wire arm *P*, which is so adjustable that its free end may be placed at any desired distance from the kathode terminal *B′*. Usually the vacuum of the tube is too high, either for the work to be done or even for the discharge to pass through the tube. The resistance of a *shunt* circuit from *A′* through *M* to *M′*, and then through *D* to *H* and thence through

FIG. 343

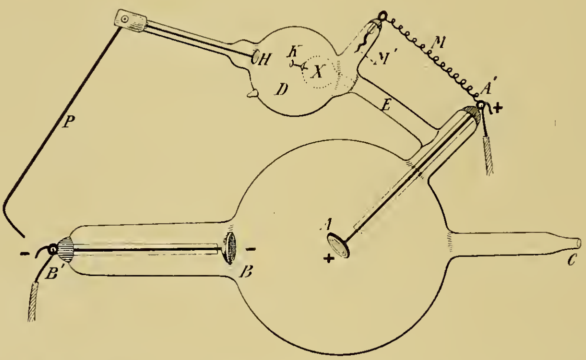


Diagram illustrating the construction of the Queen self-regulating tube and the principles of its automatic shunt regulation.

P and across the spark gap to *B′* can be varied by changing the length of the spark gap between the swivel arm *P* and *B′*. If this be shortened until the resistance through the shunt is less than through the tube, the discharge will then pass around through the shunt circuit. In so doing, a kathode stream from *H* bombards the antikathode *K* and the chemical bulb *X*, thereby generating heat sufficient to drive off the gases from the chemical, and this process will continue until the tube vacuum is lowered to a point where its resistance is slightly less than that through the regulating shunt, after which the discharge will, of course, pass through the tube only, and will continue to do so until the vacuum rises again through reabsorption of the gases by the cooled salt. By proper adjustment of the swivel arm *P*, and the length of the spark gap between *P* and *B′*, practically any desired degree of vacuum can, when thus obtained, be maintained while the tube is being operated properly, an occasional spark passing across the gap by a divergence of a part of

the charge through the regulating shunt keeping the vacuum from rising above the desired point. Care should be taken not to excite the regulator too vigorously at first, as the chemical may be heated too much, and as it continues to give off gas until cooled, the vacuum may be lowered to such an extent that the tube cannot be used, for a time at least.

Fig. 344

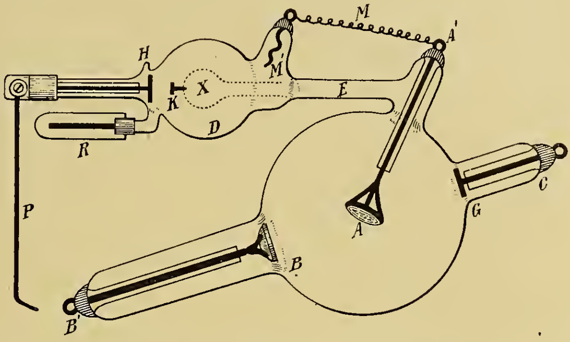


Diagram illustrating the principle of regulating the vacuum of the auxiliary regulating bulb of the Queen self-regulating tube by an osmosis regulator.

One objectionable feature of this regulator was the fact that the gas in the bulb *D* tended to disappear gradually through occlusion or otherwise, just as in any hard *x*-ray tube, so that after a time the resistance of the bulb *D* would become too high to permit regulation, or

Fig. 345

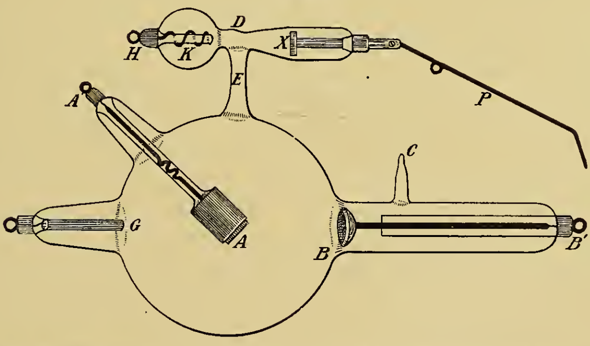


Diagram illustrating the construction of one of the types of the Müller tube and the principles of its automatic shunt regulation.

the glass would be punctured by sparks passing around the outside. The tube itself would then be useless unless a new regulator were attached. The attempt was made to overcome this difficulty by attaching an osmosis regulator *R* (Fig. 344) to the auxiliary bulb *D*.

Another modification of the shunt automatic regulator was used in the Müller tube, one of the types of which is diagrammatically represented in Fig. 345. The essential points of difference between this regulator and the previous one are (1) in the process of the evolution of the gas in the auxiliary bulb *D*, and (2) the direct communication between the latter and the tube. It will be noted that in the regulation of this tube the regulating discharge must be diverted from within the tube, the potential direction being from the anode *A* (or *G*) through *E* to the electrode *X* and swivel arm *P*. In this regulator the gas producer is the electrode *X*, a circular disk made up of very thin mica plates, in passing through which the discharge evolves sufficient heat to drive off a certain amount of gas *occluded* by the mica disk or a chemical incorporated therein. After the tube has become very hard and the disk inactive through loss of most of its gas, not only does the preliminary lowering of the vacuum require some time, but the process is apt to be continuous during the entire period of excitation of the tube. Under

Fig. 346

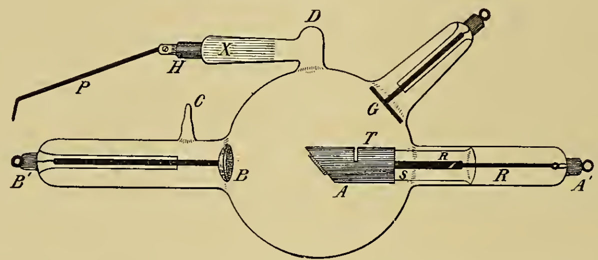


Diagram illustrating the construction of a modern type of x-ray tube of American manufacture, and showing the methods of automatic vacuum regulation and of heat conduction.

such circumstances, it may be advantageous to force the preliminary regulation by removing the negative wire from B' and connecting it directly with the regulator at the loop in the swivel arm *P*, and then forcing a few quick and moderately heavy discharges through the regulator.

An additional feature of this regulator, perhaps more useful in theory than in practice, is a device for raising the vacuum when too low. It consists of a spiral of thin palladium wire around a glass rod *K*, and connected with an external terminal, *H*. By attaching the positive wire to the latter, elevating the swivel arm *P* away from B', and passing a very light discharge through *H*, *K*, *E*, *B*, B' for several minutes, it is often possible to raise a low vacuum to a certain extent through the occlusion of some of the excess of gas by the palladium wire and by the small particles of the metal thrown off and embedded in the glass. This device possesses probably no advantages over the method to be described later, and should be used only when the vacuum has become too low *accidentally*.

Still another modification of the automatic shunt regulator (Fig. 346) is used by most American manufacturers whose tubes are popular at the present writing. In the closed extremity of the regulating bulb *D*, which communicates directly with the tube as in the previous type, is packed some asbestos impregnated with the chemical substance which liberates some of the gas it holds in chemical combination under the influence of heat generated by sparks as the discharge passes through the regulator. These tubes are constructed either with or without the swivel arm. In the latter instance automatic regulation takes place in the same way, except that the spark gap is transferred from the tube to the coil, one advantage of which is the avoidance of the annoying feature of the sparking near the patient and another, the location of the spark gap where it is often more easy of access for adjustment by the operator. A third wire is attached to a terminal at *H* and extends to an insulated terminal on the coil, the length of the gap between which and the negative terminal of the coil is regulated by means of an adjustable spark point corresponding to the swivel arm of the tube.

It should be noted in connection with all automatic shunt regulators that continuous regulation during the use of the tube diverts more or less or even all of the energy that would otherwise generate *x*-rays. Moreover, the milliammeter indicates the total amount of energy going to the tube, but it does not show how much of this is being diverted through the regulator, and cannot, therefore, furnish any reliable estimate of the volume of *x*-rays produced. In therapeutic work, a tube that is constantly regulating is not doing the amount of work, therefore, that the milliammeter reading would seem to indicate, and adequate allowance should be made in dosage estimation under such circumstances. The same may be said in connection with radiographic exposures of long duration with the light discharges from small coils; but when heavy discharges are used, if regulation should occur during the exposure, the divergence of energy is of such short duration as to make it of little importance otherwise than as a menace to the tube through cracking the regulator or forcing the vacuum too low.

Heat Conduction.—Two effects of the bombardment of the kathode stream are practically the only factors of importance, aside from time, that directly limit the amount of discharge that can be passed through a tube—the evolution of heat and the destruction of the target. By the latter is meant melting with either pitting or puncture that is likely to result from excitation by heavy discharges. It is far more likely to occur in tubes having a sharp focus of the kathode stream on the target. The tendency is greatly increased if the metal be heated to redness, although this is by no means always necessary. If a target is lacking in any adequate means for heat radiation, such as the one represented in Fig. 341, a heavy discharge from a modern coil may easily punch a hole part way or entirely through the platinum disk in a few seconds, or even one second. In the absence of a more suitable metal than platinum, the progressive increase in coil capacity necessitated some measures

for the rapid disposal of heat. The principle of all devices used for this purpose has been to construct the antikathode of considerable bulk, using additional materials that either possess large thermal capacities or are capable of rapid heat conduction from the platinum disk. One of the first means devised was the construction of a target in which the platinum disk was soldered on a solid block of copper, as shown in Fig. 347. This metal *C*, having a large thermal capacity and being a rapid heat conductor, tended to keep down the temperature of the platinum *P*. Although a vast improvement over the plain disk, even this soon proved inadequate, and was followed by the construction of the "heavy anode," the Gundelach tube (Fig. 342) being one of the earliest in which this was successfully used. The heavy anode differs essentially from the previous form simply in the addition of a long tubular iron jacket *F* (Fig. 342), into the inner end of which the copper base *E* is screwed. The object of this jacket is to increase the heat radiating surface, and it was made black at first with the view of presumably further increasing radiation, but many manufacturers have since failed to recognize any

Fig. 347

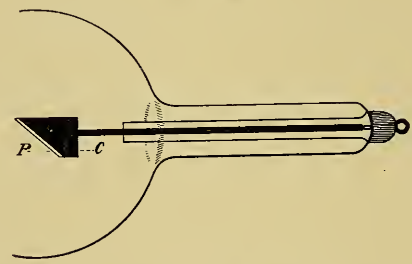


Diagram illustrating the construction of the forerunner of the "heavy anode."

advantage in the black surface and have preferred to polish or nickel plate the jacket. A modified form of the heavy anode is shown in the type of Müller tube represented in (Fig. 345), while still another modification is employed in one of the most modern types of tubes, such as is illustrated in Fig. 346. In the last example the outer half of the jacket *T* is split longitudinally, and this portion fits snugly over a tubular glass projection *S*, which aids the heavy metal conducting rod *R* in holding the whole target firmly in place. This split in the jacket, not shown in the drawing, prevents cracking of the glass support *S*, through expansion and contraction of the metal. The diagram shows an additional transverse split through the upper half. The "water-cooled" anode is another device of about the same age as the heavy anode. Its principle of heat radiation is the ideal one theoretically, but not practically. A type of water-cooled target tube is diagrammatically illustrated in Fig. 348. The platinum disk *A*, with usually a backing of another metal *O*, such as copper, forms the bottom of a water chamber constructed partly of metal *M*, and partly of glass *R*, the latter, having a funnel-shaped open-

ing F at the top or outer end, so that the chamber can readily be filled with cold water. The thermal capacity of water is greater than that of metal, and takes up the heat rapidly as it is conducted by the copper from the platinum disk. In the tube represented in the diagram the positive wire is connected to the accessory anode terminal A', from which a wire conductor S leads through the water chamber to the metal portion and target. The main objection to such tubes as a class is their awkwardness, especially as the angles at which they can be inclined are limited.

Perhaps the most popular tubes of American manufacture at this writing are several that are similar in type and construction to the one diagrammatically represented in Fig. 346, with the automatic shunt regulator, accessory anode, and heavy anode. In the tubes intended for rapid radiographic work the platinum disk is now usually reinforced at the focal point by a much smaller one (to save cost) of some other

Fig. 348

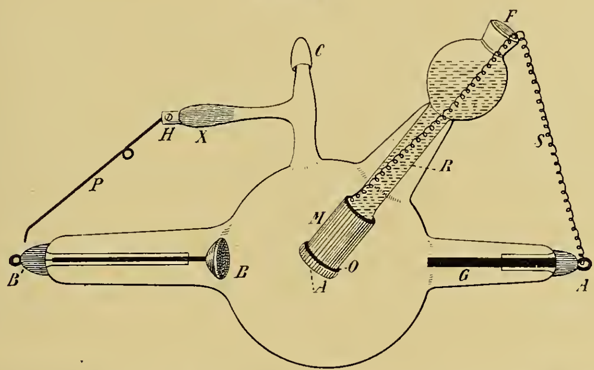


Diagram illustrating the construction of the modern type of water-cooled target tube.

metal with higher fusing point, such as 25 to 50 per cent. iridioplatinum, iridium, osmium, tantalum, etc. This is securely soldered to the platinum. Such targets add considerably to the cost of the tubes, but are a great saving in expense in the long run, and, in fact, plain platinum is no longer adequate as a target metal for tubes through which heavy secondary discharges are to be passed. Although a *sharp* focal point possesses the slight advantage of yielding a little sharper detail in pictures, it is a distinct disadvantage in rapid radiographic work for the reason that the target is likely to be dug up or pitted very soon. It is advisable, therefore, to purchase tubes with a comparatively broad focus on the target.

When a target is punctured *slowly*, an alloy is likely to be formed with the copper back of it, and which is apt to produce a very durable target, especially for therapeutic work, and some manufacturers have made practical use of this in the construction of tubes in which such an alloy

is formed on the surface of the antikathode in this way by use. A *rapid* puncture, on the other hand, allows the kathode stream to impinge directly on the baser metal before an alloy is formed, after which the tube is generally useless, and is apt to become what is termed a "cranky tube," which will be referred to later. Such tubes are apt to have a very high resistance, which after prolonged regulation drops suddenly, but rises again just as quickly. Moreover, they give off very few x-rays, and even when their resistance is high the rays are of comparatively feeble penetration. Such tubes are discolored rapidly if used, but not by a deposit of platinum.

An *air-cooled* tube has been devised somewhat on the principle of the air-cooled cylinder of the automobile, metal entirely replacing the glass part of the chamber of the water-cooled tube. Such tubes have never gained any extensive use, however.

Accessory Anode.—This was another improvement that was added to the simple primitive tube at an early period, and which has continued in use. It undoubtedly possesses certain advantages which are, however, apparent to practically only those who thoroughly understand the manipulation of x-ray tubes. An accessory anode (G, Figs. 342, 344, 345, 346, and 348) is now a part of all of the regular types of modern tubes. Its particular value lies in its effect, when used alone or with the antikathode, upon the vacuum or resistance of the tube, although its action will depend somewhat upon the manner in which the tube was exhausted and upon the length of time it has been used. As a rule, in a tube from which occluded gases have not been exhausted to any great extent there is more occluded gas in the greater bulk of metal of the anode than in the much less bulky accessory anode. Such a tube, if exhausted to a "medium" or a "soft" vacuum, will run *longer* as a "medium" or a "soft" tube if the anode *alone* is used than if only the accessory anode is used. On the other hand, if only the accessory anode be used, the tube may run even "softer" *at first*, but it does not continue to run "soft" so long as it would if operated on the anode alone, because of the less bulk of metal and occluded gas in the former, and also for the reason that accessory anodes are usually made of aluminum, from which gases are expelled more quickly than from the metals of the antikathode. As a rule, it is better to begin by using only the anode terminal, keeping the other electrode in reserve, until the tube begins to work a little too "hard," and then to connect both terminals, and thus prolong the existence of the desirable qualities of the tube. The accessory anode is sometimes of use also in raising the vacuum when it has accidentally become too low, as will be explained later.

With proper care a good radiographic tube should serve a period of usefulness sufficient for several hundred exposures, barring unavoidable accidents, of course.

The varieties of tubes made in the past have been far too numerous to permit of a description of more than a single example of each standard type, such as those referred to in showing the gradual development in

tube construction to keep pace with the requirements. Mention might be made of a few unusual types that have been devised from time to time to meet special requirements. As a rule, however, the value of such tubes has existed in theory rather than in practice.

Double Focus Tube.—Before special attention was given in coil construction to means of minimizing the inverse energy, the attempt was made to overcome this obstacle by the use of a specially designed tube having two anodes and two kathodes in order to utilize the current in both directions. Such tubes have never given much satisfaction, and are not to be considered of any value at the present time.

Cavity Tubes.—Numerous varieties of this general class of tubes have been devised with the purpose in view of making direct applications within cavities such as the vagina, rectum, and throat. Theoretically, they have been intended to overcome the difficulties encountered in any method of using the ordinary type of tube. In the latter the anodal source of rays must of necessity be at a considerable distance from the

Fig. 349

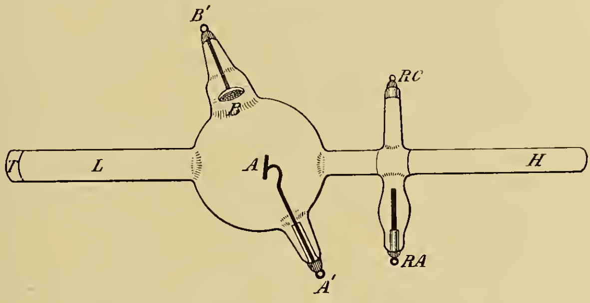


Diagram illustrating the first type of cavity tube.

part to be treated, and as the rays must pass through a speculum of some kind, only a small column of them can be directed on any surface which also must be of very limited extent. Moreover, the anode, the long axis of the speculum, and the part treated must be in the same straight line, which is not only difficult of adjustment, but not readily maintained, as the slightest movement of patient, speculum, or tube is often likely to cut off the whole column of rays from the part being treated. Unfortunately cavity tubes, as a class, are inefficient and of little practical value. In their principles of construction and operation, they follow two general types, which are diagrammatically illustrated in Figs. 349 and 350.

In the type represented in Fig. 349, the wires are attached to the anode and kathode terminals A' and B' respectively. Rays are projected from the front of the anode A, and a column of them through the prolongation T–L. All parts of the tube except the end of this prolongation T are made of lead glass, which is supposed to be opaque to rays of such penetration as are generated, hence none are supposed

to escape except through the transparent glass end of the prolongation at *T*, which is introduced into the cavity to be treated. The tube is held in place by an attendant who grasps the handle *H*, the interior of which does not communicate with that of the tube, and not having a vacuum, it is, therefore, insulated. Unless the vacuum be kept low, the lead glass is of little protection, if it is so under any conditions under which rays of suitable penetration are produced. Moreover, too high a resistance is attended by the risks of shocks to the patient or attendant holding the tube. To prevent too high a vacuum these tubes are supplied with a regulating device which is operated by attaching the positive wire at *R–A*, and the negative wire at *R–C*, wherein lies the gas-producing chemical, and then passing a light discharge through. For these tubes to be in any way efficient, the lesion must be superficial and of small extent, for their output cannot be of much penetration or volume. Their only possible advantage would seem to be in always keeping the rays directed upon the area exposed, which is the greatest

Fig. 350

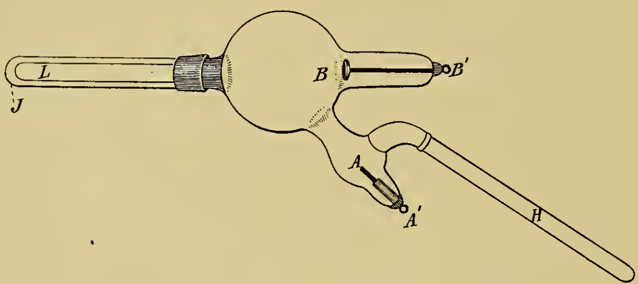


Diagram illustrating the second type of cavity tube.

difficulty attending the use of the ordinary type of tube and speculum. The source of rays can certainly not be brought much if any closer than with the latter.

In cavity tubes of the type represented in Fig. 350 the target is not the ancde *A*, but the end of the glass projecting tube *L*, upon which the kathode stream from *B* is made to impinge. As the heat generated by the impact at this point would be sufficient to melt a hole through the glass in a few seconds, the entire projecting tube is enclosed in a glass water jacket, *J*, which permits of the tube being run on a very light discharge for from five to fifteen minutes before becoming too hot for the patient to bear. The positive and negative wires are attached to the anode and kathcde terminals, *A′* and *B′* respectively, and, like the previous type, the tube is held in place by an assistant grasping the insulated handle *H*. The principle is ideal theoretically, but the output of rays is so feeble in penetration and small in volume as to render such tubes of little practical value, although it is claimed for them that the great reduction in distance makes up for the lack of volume in the

output. With such feeble penetration the glass and water together must certainly absorb a large proportion of the rays generated.

In a modification of this type a platinum target is placed in the end of the projecting tube *L*, but the field of exposure is thereby lessened one-half, as the rays can be projected in front of only one side of the disk.

MANIPULATION OF APPARATUS

The Tube.—The proper manipulation of *x*-ray apparatus is practically a matter of using such a tube as is adapted to the work to be done, and of so adjusting it and the mechanism of the rest of the apparatus that the tube will be properly excited. The *x*-ray output from any tube is made up of varying proportions of rays of widely different degrees of penetration, with usually a preponderance of those of one certain degree, the proportion of which, however, varies both in different tubes and in the same tube under different conditions. For radiographic work it is essential that the penetration of the major portion of the output be of such a degree as to penetrate the part examined, in order that the rays may reach the sensitized film of the plate, and yet not too great, or they will pass through both dense and more transparent structures alike, giving poor or insufficient contrast to the shadows in the negative. In *therapeutic* work the effect of the rays is manifest, for the most part at least, in those tissues in which they are absorbed, and it is essential, therefore, to use such a tube and to manipulate it and the rest of the apparatus in such a manner that the preponderance of the rays generated will have such penetration that they will not only reach the depth of the tissues to be treated, but will be absorbed by the latter and not penetrate beyond to any great extent.

The tube used should always be one adapted for the work it is expected to accomplish, for a single tube is no more suited for all varieties of *x*-ray work than is the same clothing proper for both the hottest days of summer and the coldest of winter.

A perfect *x*-ray tube has never been devised, and probably never will be made, and for this reason, at least, absolute perfection in manipulation cannot be realized. With any tube and apparatus, however, a certain approximate degree of perfection in their operation is possible, but its realization otherwise than by chance depends largely upon attention to the following factors: (1) In obtaining an output in which the greatest proportion of rays is of such a degree of penetration as to meet the requirements. (2) The maintenance of constancy in the penetration of such an output. (3) The delivery of a requisite volume of *x*-rays.

PENETRATION

1. In a general way the degree of penetration of the large proportion of the rays evolved depends largely upon the degree of vacuum or the resistance of the tube. It has been the experience of many persons of

authority that there is a certain resistance at which in good tubes a larger proportion of rays of one degree of penetration are given off than at any other, and this resistance is generally conceded to be that of the so-called "medium" tube, or equivalent to that of from 2.5 to 4 inches of spark gap. The penetrating quality of the rays from such tubes would correspond to about number 4 or 5 on the Walter scale, to be described later. It should not be inferred that such tubes and their output are the most suitable for all kinds of x-ray work, for such is not the case, but when rays of such penetration as such a tube gives are those most desirable for the work to be done, particular advantages are afforded, first, because the output of such a tube is especially rich in rays of the proper penetration, entailing a minimum waste of x-ray energy; secondly, because in radiographic work such conditions are conducive to the greatest contrast in shadows of tissues of different densities; and thirdly, there is, perhaps, a smaller proportion of soft rays given off to induce a dermatitis. For superficial applications this penetration is too great, a resistance equivalent to from one-half to two inches of spark gap being better adapted to the purpose. Fortunately, the penetration of rays from "medium" tubes gives the latter a wide range of usefulness, as they are well adapted for most *deep* therapeutic applications as well as for a large portion of radiographic work, such as in examinations of the extremities, the chest, and abdomens of ordinary thickness. In these examinations wherein the deepest penetration is not required the comparatively low resistance of such tubes makes it possible to use heavier charges through them and to obtain a greater volume of rays than is possible with the somewhat harder tubes with a resistance of from 4 to 6 inches of spark gap, which are often required for deeper work, such as in radiographing thick hips and abdomens and examining the accessory sinuses. It is always best to use the tube having the lowest resistance consistent with the thickness of the part in order to get the best details, otherwise the pictures tend to be flat.

Determination and Control of Penetration.—Since penetration is one of the two most important factors in accurate x-ray work, it is essential to have some means of determining and of controlling it. Although neither can be done with exactness, there are two general methods of estimating the penetration of the major portion of the output. By the one which is most convenient and most extensively used, and just referred to, it is estimated *indirectly* in terms of the internal resistance of the tube, which in its turn is indicated by the length of a spark gap of equal resistance to the exciting secondary discharge. This method is fairly reliable, although by no means accurate, and is based upon the fact that in practically all good tubes a fairly constant ratio exists between the tube resistance and the penetration of its rays. The accuracy of this method may be influenced by atmospheric conditions, especially humidity, by ionization of air in the spark gap, and by certain peculiarities of the tubes.

In the second general method penetration is estimated directly.

Numerous devices have been originated for the purpose, but only a few of them are worthy of mention here.

Perhaps the oldest method was for the operator to judge the penetration by looking at his hand or some other part through the fluoroscope. This may possess some advantages, being at least convenient, but it is a most dangerous practice, which in these days, although not obsolete, is significant of foolhardiness or of ignorance.

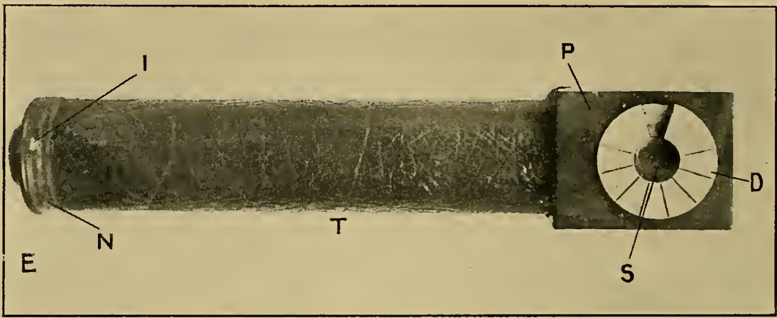
Walter Skiameter.—The Walter skiameter is one of the most practical and really useful examples of the type of instruments devised for the purpose. One of its essential parts consists of eight platinum disks, the thickness of each of which increases from the first to the eighth in geometrical progression. The penetration of the rays from any tube is designated in terms of the number of the thickest disk they will readily pass through and light up a fluoroscopic screen, which is a second essential part of the device. For example, the softest or least penetrating rays it would record would penetrate only the thinnest or number one disk, and such rays would be termed "Walter one" rays, and likewise the tube producing such an output is usually designated as a "Walter one" tube. Rays of a little deeper penetration would pass through both number one and number two disks, and would be "Walter two" rays, from a "Walter two" tube, and so on up to the deepest penetrating rays which would go through all eight of the disks.

Benoist Radiochromometer.—This, together with its several modifications, is another ingenious instrument of this type, which possesses some practical usefulness. The several parts of one of its modified forms are represented in Fig. 351, *A*, *B*, and *C*, and consist primarily of a telescopic tube *T*, with an opening at *E*, through which the observer looks at the reflection at the other end in a mirror *M*, of the fluorescent screen *F*, when the latter is lighted up by rays passing through the circular disk of metal *S–D*, on the outside of this screen. One of the essential parts is the circular disk of silver *S*, 0.11 millimeter in thickness, surrounded by a series of 12 sector-shaped aluminum disks *D*, which increase in thickness regularly, thus presenting a step-like appearance. The silver disk is transparent to rays of any penetration which will pass through any of the aluminum disks. By means of a diaphragm *X*, at the far end of the telescopic tube, the portion of the screen illuminated by rays passing through the silver disk is always in view, but only a portion corresponding to one of the aluminum disks can be in view at one time, though any one of these can be brought into view by turning the diaphragm and opening *Y* around by means of the attachment *I*, which at the same time indicates on the scale *N* the number of the aluminum disk represented by the lighted sector on the screen. When using the instrument, the metal disks *D–S* are placed directly in front of the tube, and the observer, looking through the aperture, turns the indicator *I* around until the degree of fluorescence in one of the sectors corresponds to that of the central portion representing the standard silver disk. The number of the aluminum disk thus indicated designates

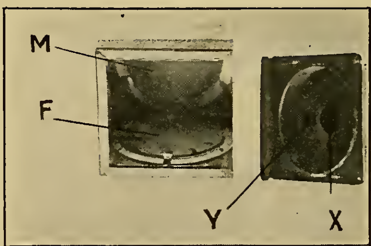
the penetration of the rays from the tube in terms of the Benoist scale. The standard central disk is made of silver because this is one of a group of metals having nearly the same atomic weights, which vary the least in the amount of obstruction they offer to rays through a wide range of penetration.

Neither of these instruments furnishes more than an approximate estimate of the penetration of the larger proportion of the output, nor does either indicate just what proportion of the output this represents.

FIG. 351



A



B C

Parts of a modified form of the Benoist penetrometer: *A*, instrument intact; *B*, interior view of penetrometer proper *P*, showing mirror *M*, and fluorescent screen *F*; *C*, interior view of end of telescopic portion *T*, showing diaphragm *X*, *Y*, operated by indicator *I*.

MAINTENANCE OF CONSTANCY IN PENETRATION

2. Penetration being largely dependent upon the resistance of the tube, its maintenance at a constant degree throughout the period of excitation must be largely a matter of the maintenance of a constant resistance. A constant vacuum in a tube cannot be maintained indefinitely, but must fall sooner or later in any tube, with a simultaneous and corresponding decrease in the degree of penetration of the output. This means lessened efficiency of the tube, and had it at first been

delivering the proper quality of output for a radiographic exposure, the rays now delivered would lack sufficient penetration to reach the sensitized film; or in the case of a deep therapeutic application, not only would there be inefficiency, but the increased percentage of soft rays would endanger a dermatitis.

Constancy in penetration is mainly dependent, through constancy of resistance, upon the following factors: Heat dissipation, adequate exhaustion, the rate of evolution of occluded gases, the nature of the residual gases, the kind and proportions of the metals composing the electrodes, and lastly, and the most important of all, perhaps, the proper manipulation of the tube.

Heat Dissipation.—Heat is both an unavoidable by-product in x-ray production and the grestest obstacle in x-ray work. Its deleterious effects may be manifest in two ways: (1) Upon the tube either in damage to the target or cracking of the glass; (2) it is the immediate cause of the drop in the vacuum attending excessive excitation, through the expulsion of an excess of occluded gases from the heated electrodes. These effects may be lessened or retarded somewhat through efforts directed toward more rapid heat dissipation, and which may be classed as follows: Special construction of the electrodes, and especially the target, as previously explained; increased size of the tube, by which a greater area of glass surface is exposed for radiating heat that is likely to crack it or drive out gas occluded by the platinum deposit; and the avoidance of obstacles to irradiation of heat as much as possible, namely, high temperature of the room and inadequate ventilation in tube shields. Although heat dissipation is greatly facilitated by increasing the size of the tube, the size must be limited, on the other hand, by the unwieldiness and increased cost. Tubes of six or seven inches diameter are the most satisfactory on the whole.

Adequate Exhaustion.—Reference has been made to the importance of driving out the excess of occluded gases during the process of exhaustion. Only the *excess* should be removed, however, as a certain amount of occluded gases is essential to the life and the efficiency of the tube.

Rate of Evolution of Occluded Gases.—Any "well-seasoned" tube of a reasonable degree of efficiency for performing the particular work for which it is best adapted may be excited by a certain amount of current for a reasonably long period of time without having its resistance or vacuum lowered to any great extent, and, in fact, the tube may be depended upon to act in this way at any time. The term *normal current* has been suggested for the particular amount of current by which any given tube may be excited for the longest period without any material change in its resistance or vacuum. Should there be any *increase* in this amount, however, the resistance will drop before the termination of this period, because the increased heat thereby generated causes too rapid an evolution of the gases occluded in the metals and glass walls. A *decrease* in the current, on the other hand, is very apt to *increase* the resistance, because it favors an *occlusion* of gas in excess of the degree

of evolution, whereby the available supply of free gas is diminished. A new supply must then be obtained, and the regulator comes into service. The *normal current* of a tube is more or less closely related to the process termed *seasoning*, the exact interpretation of which is somewhat in dispute.

A *seasoned* tube might be described as one in which the proper balance between the evolution of occluded gases and the occlusion of the free gas is not materially disturbed, especially when excited by a *normal current*, except by excessive or prolonged excitation. Such a tube will likewise withstand a *heavy charge* for a *short* time without its vacuum being immediately lowered, and a seasoned tube is, therefore, essential for radiographic work. The vacuum may drop immediately after the exposure, however, but the excess of gas is usually reabsorbed as the electrodes and glass cool. For this reason a radiographic tube should be given a reasonably long rest after each exposure that is likely to have imposed a strain approaching the limit of the tube's capacity. As previously stated, the deposit of platinum in the glass walls is an important factor in the process of seasoning, and although a perfectly new tube may be practically a "seasoned" one, most of them are not, so that, as a rule, a tube should be used in moderation for light work until a certain excess of occluded gases becomes more permanently occluded.

Nature of Residual Gases.—The exact nature of either the free or the occluded gases has an important bearing upon the ray producing properties of the tube. Those usually present are hydrogen, oxygen, nitrogen, or air, all of which are thoroughly efficient, but often in one way or another unusual gases, such as certain of the rarer atmospheric constituents—argon, helium, etc., and certain others derived from the asbestos of the regulator—may become sufficiently prevalent to render the tube unreliable or even useless. This is said to be one of the factors in the production of the so-called "cranky tube."

Composition of the Electrodes.—Both the kind of metals and their relative proportions are important in the makeup of the tube. Those usually employed for electrodes—aluminum, iron, copper, and platinum, or its equivalent—are used because of their special adaptation. As an instance of the importance of the proper relative proportions, it is said that in tubes in which the proportion of platinum to copper is too little an excessive deposit of the latter may precede the deposition of platinum and is apt to render the tube cranky.

Proper Manipulation of the Tube.—Such factors as are concerned in the proper manipulation of a tube or those procedures through which it is accomplished, especially in obtaining maximum efficiency for the work to be done, may be conveniently arranged for subsequent discussion as follows: The appropriate vacuum, regulation, raising the vacuum, rest, appropriate use, suppression of inverse discharge, variations in primary inductance, and the avoidance of secondary and indirect rays.

The Appropriate Vacuum.—Attention has been called to the fact that, for radiographic exposures particularly, the tube should have the lowest

vacuum resistance consistent with the production of rays of the desired degree of penetration, because the lower the resistance of the tube the heavier can be the charge passed through it and the greater the resulting output of rays, which depends upon the volume of the charge passing through the tube and the amount of gas available to conduct it. The *resistance* of the tube increases in *direct* proportion to any increase in the volume of the exciting current, because of the greater amount of gas required for ionization and its conduction. The effect is *comparable* to a rise in vacuum, but as there is no material change in the latter, the term "resistance" should be used instead of "vacuum" in this connection. As an example, if a certain tube should indicate a resistance equal to a three-inch spark gap when excited by a charge of 1 to 2 milliamperes, in order to increase this to 10, 20, or 40 milliamperes, and still obtain rays of the *same degree of penetration*, it would be necessary to lower the vacuum somewhat by means of the regulator, being careful not to drive out too much gas or to heat the tube unnecessarily in so doing. Then the exposure should be as short as possible, as *heat* production increases in proportion to the *square* of the current increase, and consequently the vacuum or resistance will not remain stationary long.

Regulation.—The object of lowering the vacuum in this way for heavy charges is to liberate just enough gas to *start* the tube well, after which the great amount of heat evolved will usually suffice to keep the vacuum down to the desired point. There is a peculiar tendency on the part of some tubes for their resistance to rise suddenly immediately after their excitation with a heavy charge begins, although the vacuum was apparently right beforehand. This should always be borne in mind as a peculiar feature of that particular tube, and care should be taken to avoid if possible a heavy charge passing through the regulator, on account of the risk of cracking the latter or of lowering the vacuum too much. Ordinary preliminary regulation should be done with *light* charges *just before* the exposure is made. During regulation the spark point should not be placed too near the kathode terminal, especially in the new tube, and never nearer than 3 or 4 inches during a radiographic exposure. This does not apply to therapeutic work, as then light charges only are used anyway. Should excessive regulation through a heavy charge occur in a *seasoned* tube during a radiographic exposure and while the electrodes are *hot*, they are apt to occlude too much of the excess of gas on cooling, and the tube will thereafter behave somewhat after the manner of a new one that has been inadequately exhausted; that is, during subsequent exposures the metals will begin to evolve gas too soon and in excessive quantities. Such a tube to be of any future use will require careful "re-seasoning."

Raising the Vacuum.—Should the vacuum of a medium or a hard and seasoned tube accidentally become too low, it may be recovered, provided there is not a small crack or puncture in the glass, or more gas has not been driven out of the regulator than can be subsequently taken up by the metals of the electrodes and the platinum deposit in the glass.

The principle of all methods of recovering a vacuum accidentally lowered too far is a satisfactory redistribution of the excess of gas. One way is to run the tube *very lightly* for a few minutes at a time several times a day, with a view of warming up the electrodes sufficiently to permit them to absorb a little of the free gas, but not enough to allow them to part with any of their occluded gas. Another good plan is to run a very light charge in the *reverse* direction, with either the antikathode or the accessory anode alone in circuit, but not both. Should there be too much gas occluded in the antikathode, it should not be used in this way until the excess of *free* gas in the tube is taken up. The above methods may be used successively, but preferably not simultaneously. If a lowered vacuum can be raised to a certain point, but no farther, there is probably a small crack or puncture somewhere, which may or may not be visible, but which allows air to enter slowly until the vacuum falls to a certain point, beyond which atmospheric pressure is insufficient to force more air through.

Rest.—Reference has been made to the necessity of allowing a tube to rest after a vigorous radiographic exposure. This is essential in order to permit complete cooling and a proper readjustment of occluded and any excess of free gases. This is especially important in particularly good tubes which are especially adapted to the most difficult and delicate work, and for which they should be used solely. The ordinary routine work should be imposed upon tubes capable of withstanding hard usage without damage, and yet which are not capable of accomplishing the most difficult or the most delicate work satisfactorily.

Appropriate Use.—In connection with therapeutic work it should not be necessary to give detailed explanation of the reasons for using soft tubes in superficial applications and medium or occasionally a hard one for deeper work. Unfortunately there are many who pretend to treat patients but who are apparently ignorant of this basic principle of x-ray therapeutics.

Good *radiographic* tubes require special care in their use. They should *never* be used for treatment or fluoroscopic work after having been once adequately seasoned, although this process is often best effected through light therapeutic work. A good picture tube is soon spoiled by continuous use in treatment. In the first place, most tubes become more or less adapted to the conditions imposed by one particular kind of work, even in radiography, and secondly, therapeutic applications tend to blacken a tube quickly and exhaust its regulator, making it too hard. Moreover, tubes may become adapted to use on one coil and will not work well with another. This is probably due largely to the differences in voltage, inverse, and interrupters.

Suppression of Inverse Discharge.—Our only means, so far, of obtaining an exciting current of sufficiently high potential for x-ray purposes without the concomitant production of an inverse discharge lies in the use of the static machine, which unfortunately is no longer able to fulfil the requirements otherwise. It is impossible to *produce* an induction

current without the simultaneous production of an inverse discharge, and this is in x-ray work an obstacle that must be overcome, because it prematurely blackens the tube and with a more or less undesirable deposit; it tends to lower the vacuum more rapidly during use; it ultimately hardens the tube too rapidly; and tends to increase the indirect and secondary radiation from the tube. Fortunately this obstacle can be overcome in either one of two ways—either by eliminating or by suppressing the inverse. The easier and more satisfactory method is that of mechanically *eliminating* it as an obstacle and at the same time *utilizing* its energy, as is done in the *transformer* type of induction apparatus (p. 416). In connection with the older *coil* type, however, all that can be accomplished through the agency of the machine itself is to render the *suppression* of the inverse easier, which is left to the operator to accomplish by means of suitable resistance placed in the secondary circuit sufficient to suppress the lower potential inverse but not the higher potential break discharge. The resistance of the x-ray tube itself may be sufficient, but usually it is not, especially in radiographic work, one important reason being the fact that practically all tubes offer *less* resistance to a discharge going through them in the *reverse* than in the normal direction. Therefore it is usually necessary to impose additional resistance in series with the tube in order to make up the deficiency.

Were it not for the fact that the inverse of practically all coils is of less potential than the break discharge, the *suppression* of the inverse would be a most difficult matter. There is more difference in the potentials in x-ray coils, perhaps than in those made for other purposes, for the one reason especially, that the interrupters of the former are specially constructed with a view of making the break quicker than the make, and the quicker these changes the higher the secondary voltage. But the coils themselves can be so constructed as to further lessen the inverse potential, as, for instance, by so adjusting the relative proportions of the primary and secondary windings as to reduce the secondary voltage to the minimum necessary for the excitation of any tube. There is thereby derived the additional advantage of an accompanying increase in the secondary amperage. This principle is embodied in the modern type of coil, which gives a comparatively short but very thick spark. Further reference to this subject will be found in connection with that of *variable inductance*.

Should the tube's resistance not be sufficient to *suppress* the inverse, there must be added just enough to make up the deficiency, but no more than enough, as it is not only unnecessary but a disadvantage, because the volume of the exciting current is apt to be lessened by too much resistance in the secondary circuit, and it is apt to mislead the operator in the estimation of the resistance of his tube by the spark gap method. There are two devices for interposing additional resistance—the *series spark gap* and the *valve tube*. The former alone may suffice, but the use of the valve tube, either alone or in conjunction, insures greater precision.

The valve or ventril tube (Fig. 352), which in principle is nothing more than a simple type of vacuum tube operated in the *reverse* direction, is usually placed in series between the *negative* terminal of the coil and the *kathode* terminal of the x-ray tube, the wire from the latter being attached to B', and the one from the coil to A'. Thus the *direct* discharge through the x-ray tube is made to pass through the valve in the *reverse* direction, at least from the standpoint of an x-ray tube. Hence it offers *less* resistance to the true *direct* discharge, because, as previously stated, a tube offers less resistance to a current in the reverse than in the normal direction through it. At the same time, the valve receives the *true inverse* (of the x-ray tube) in its own normal direction or that of its *greater resistance*. The exact construction of the valve tube is not a matter of so much importance, and, in fact, a *soft* Gundelach tube (Fig. 342) would, if *reversed*, answer the purpose very well. A valve tube must be provided with some means of vacuum regulation (Fig. 352, *D*), for to render accurate service its vacuum must be appropriately adjusted to the varying conditions imposed. If it be used *alone*, its resistance to

Fig. 352

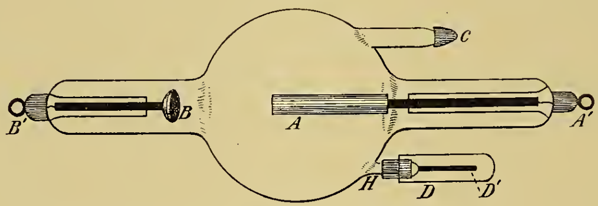


Diagram illustrating the construction of the valve or ventril tube.

the inverse must be adjusted to variations in the inverse potential and also those in the reverse resistance of the x-ray tube, and this must be done by raising or lowering its vacuum. For example, it should be lower for a hard than for a medium or a soft x-ray tube. If series spark gaps are used in conjunction, their adjustment alone, which is comparatively a very simple matter, will usually suffice.

According to a plan suggested by Dr. Willey for the accurate adjustment of the resistance for the suppression of inverse, and which may be done for each set of conditions under which any coil is used, the *inverse potential* for each set is experimentally determined, and then the additional resistance needed for each x-ray tube used is easily calculated. The first step is to obtain the particular coil condition desired by adjusting the mechanism so that a discharge of the milliamperage and voltage desired for the work will be delivered. The next step is to determine the potential or sparking distance of the inverse these conditions will yield, and which is to be suppressed. To do this, the valve tube V (Fig. 353) is placed in the circuit with a *soft* x-ray tube X, which is placed *in the reverse direction*, so that it offers a greater resistance to

the *inverse*, and this resistance together with that of the valve will probably be sufficient to suppress the inverse.

The valve tube is connected with a *parallel spark gap S*. By approximating the *parallel* spark gap of the *coil CC* until a spark will just jump across, the *reverse resistance* of the *x*-ray tube in terms of spark length will be obtained. This should be recorded, although it has nothing to do directly with the inverse potential.

The next procedure is to change the tube *X* to its normal direction *X′*, and then after starting the current the parallel spark gap *S′* is adjusted until a spark will just jump across instead of the *inverse* discharge going through the valve tube *V′*. The direct discharge will continue to pass through, however, because of the less resistance offered to it in

Fig. 353

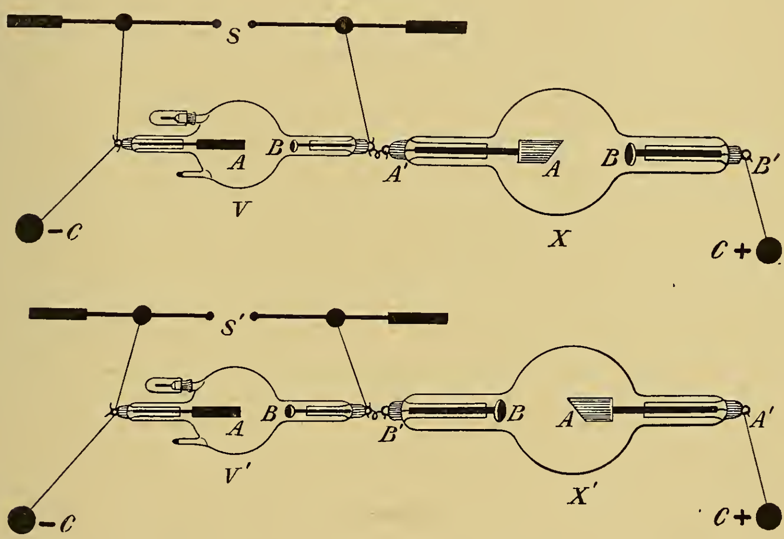


Diagram illustrating Willey's method of determining inverse potential or spark length.

the reverse direction. The length of this gap *S′*, plus the *reverse resistance* of the *x*-ray *tube X*, previously obtained, equals the *spark length or potential* of the *inverse* discharge of the coil under the existing conditions of milliamperage and voltage of the secondary.

The final step is to adjust the *vacuum* of the *valve tube* and the lengths of the *series spark gaps* so that their combined resistance, plus the *reverse* resistance of the *x-ray tube* is a *little more* than that of the *equivalent spark length of the inverse.* In this way the inverse spark length can be determined for any coil conditions (milliamperage and voltage) desirable, and the proper adjustment needed made for any *x*-ray tube can be computed by simply subtracting from the inverse spark length under the given coil conditions the reverse resistance of that tube under

the same coil conditions. The difference is the amount of resistance to the inverse that must be rendered by the valve tube and series spark gaps.

Variable Inductance.—It has been stated that a tube should have the lowest resistance consistent with the production of rays of the proper penetration for the work to be done, for two reasons: (1) Because such an output insures the greatest amount of tissue differentiation by the shadows in the plate; and (2) because the less the resistance of the tube, the greater the volume of current that can be passed through, and the greater the resulting x-ray volume. It is also advisable to use the *lowest potential* secondary discharge consistent with the resistance of the tube and the penetration desired (voltage governs initial velocity of corpuscles) for two reasons also: (1) Because an unnecessarily high voltage means a waste of energy at the expense of *volume* or *amperage*, and consequently of x-ray volume; and (2) in a coil, the lower the potential used the less will be the voltage of the *inverse*. In general x-ray work it is necessary to use hard, medium, and soft tubes, and the secondary voltage best adapted to the soft tube would not be sufficiently high for the proper operation of a hard tube; and the appropriate potential for a hard tube would not only mean a waste of energy at the expense of amperage and x-ray volume if applied to a soft tube, but the *inverse voltage* (from a coil) would be undesirably high and harder to eliminate because of the lower resistance of the tube. As it is hardly feasible to have several coils or transformers to deliver the different voltages that may be required, it is most desirable to possess some means whereby the secondary potential of any one machine can be varied or adapted to each requirement. Fortunately we now possess the means of accomplishing this in the *variable primary inductance.*

The secondary potential of any induction apparatus depends mainly upon three factors—(1) the primary voltage; (2) the distance between the primary winding and core and the secondary windings; and (3) upon the relative proportions of the turns of the primary to those of the secondary windings. A proportionate *increase in both* primary and secondary turns tends to increase the secondary potential, which, however, is more or less counteracted because of the high resistance of the fine gauge wire used in all secondary windings. Secondary potential is also increased, and to a still greater extent, by a *relative increase* in the *secondary windings alone,* but here again the attending increase in resistance imposes a limit upon the extent to which this can be carried. Fortunately, however, the secondary voltage may also be increased by a *relative decrease* in the *primary* windings, and, moreover, without the undesirable increase in secondary resistance. This is an important principle that has been embodied in the construction of all modern induction apparatus except the smaller coils. The relative proportions of primary and secondary windings are first adjusted with the object of the machine delivering a certain maximum voltage. The primary winding is then tapped at certain intervals, and it is practically divided into

several sections thereby, as each tap is connected with one of the points of a multiple contact switch, so that any one or more of the sections of the primary may be placed in series with the primary circuit. In this way the relative proportions of primary to secondary windings may be very conveniently increased or decreased as desired. By *decreasing* the primary turns (comparable with an *increase* of the secondary), the secondary *voltage* is *increased,* and by *increasing the primary inductance* or turns, the secondary *voltage* is *decreased.* Moreover, an increase in primary inductance has an additional tendency to lessen the voltage of the *inverse,* because it increases the *self induction* in the primary and the *make* self induction, which is opposite in direction to the primary current, is in the same direction as the inverse, which it tends, therefore, to oppose.

Indirect and Secondary Radiation.—Depending upon their points of emanation and exact manner of production, three distinct types of Röntgen rays are recognized—direct, indirect, and secondary. The term *direct radiation* applies to the normal output of a tube, or to all rays emanating from the *target* upon which the kathode stream is directed. *Indirect* rays are those that emanate from other parts of the tube, and to some extent they comprise an undesirable but unavoidable portion of the output of every tube. They emanate from any portion of the tube other than the target upon which negative corpuscles impinge, mostly from the glass walls of the anterior hemisphere, the corpuscles striking here being for the most part deflected from the kathode stream. The comparatively large volume of indirect rays from this source can be readily realized when we consider that at least 10 per cent. of the heat evolved by excitation comes from the glass walls of the tube, especially from the anterior or active hemisphere, and as this part of the glass could not be heated so much and so rapidly by radiation from the electrodes, corpuscular impact must be largely responsible, especially as this is the most actively fluorescent part of the tube and the fluorescence arises from the impact of corpuscles upon the glass. No doubt a smaller proportion of the indirect rays are the result of impact of *secondary* kathode streams coming from other parts of the tube than the kathode. Moreover, the presence of an *inverse* is undoubtedly responsible for indirect radiation, as it would at least cause the expulsion of negative corpuscles from the positive electrode. Therefore, an inverse discharge passing through the tube tends to increase indirect radiation. The penetration of indirect rays would, of course, depend upon the same factors as that of the direct radiation—the velocity of the corpuscle, or the initial force given by potential and the amount of impediment due to the degree of vacuum. There is, perhaps, less uniformity of penetration of indirect than of direct rays, and those arising from an inverse must be much less penetrating than the latter because of the less potential of the inverse.

Secondary radiation is a term applied to such rays as emanate from surfaces, objects, or matter upon which direct or even indirect rays

impinge. Naturally they are given off from the various parts of the tube, though not to the extent of indirect rays. Their origin outside the tube is of far greater moment, for they emanate from all parts of the room and all objects therein that are exposed to the rays coming from the tube. Consequently they are a constant and altogether too frequently disregarded source of danger to the x-ray operator, especially as they are not deeply penetrating. Nothing but absolute protection, as by being in another room and with a lead partition between him and the tube, or inside a safe lead booth in the x-ray room, will safeguard the operator against the dangers attending his exposure to these secondary rays. A lead booth, in which are placed all controlling switches and other devices, is perhaps preferable, but such a means of protection will not insure against ultimate immunity from those too well-known misfortunes of operators in the past unless constructed with a thick (one-eighth inch) lead wall facing the tube and somewhat thinner lead on all other sides and also *over the top.* Tube shields and simple lead *screens do not protect* the operator from secondary radiation.

Secondary rays emanate also from the tissues of the body through which direct rays are passing, and hydrocarbons being particularly efficient producers, secondary radiation arising within the body becomes an additional obstacle in the radiographic examination of a stout subject, as the rays so produced tend to prevent sharp contrasts and lessen detail.

Indirect rays are especially objectionable in connection with radiographic work, as they have sufficient volume and penetration to materially interfere with clear detail. For coming, as they do, from all parts of the tube, they destroy the sharp outlines of the shadows made by the direct rays coming from one source—the target. Fortunately they may be largely eradicated through the use of the lead diaphragm, and the smaller the aperture or the more indirect radiation cut out the clearer will be the picture, especially in respect to the details of soft structures such as the kidney and the more elusive uric acid calculus.

ESTIMATION OF X-RAY VOLUME

At the time of this writing no method has as yet been devised whereby the volume of the x-ray output from an x-ray tube can be accurately measured, nor have any of the more or less ingenious instruments or other devices designed or used for the purpose been even generally regarded as satisfactory. In fact, the majority of them, if not too inaccurate, are too impracticable, and only those that have merited any extensive practical use will be mentioned here. In considering exactness, one important fact should be borne in mind, namely, that no method of estimating x-ray volume can be regarded as exact unless it embodies some means of determining at the same time the relative proportion of at least those rays of a certain degree of penetration that constitute the

preponderance of the output. Certainly the determination of the proportionate volumes of the rays of each degree of penetration comprising the output of a tube would be a procedure of too great complexity to be practicable.

A means of exact volumetric estimation is most needed, no doubt, in therapeutic work, especially in connection with superficial applications, as, for example, in the treatment of many dermatological lesions. Moreover, it is often necessary to carry dosage to the closest possible limit of safety to healthy tissues in order to obtain the desired destructive effect upon diseased cells, and the less dependable is our volumetric factor in dosage, the more chances are we taking of doing injury or of doing no good. Notwithstanding the claims for reasonably exact volumetric estimation made by many Röntgen therapeutists, especially abroad, the determination of this factor continues to be, generally speaking, an approximate one only, and one in which the degree of exactness attainable is to a large extent dependable upon experience and skill.

Practically all of the methods so far devised may be included under the following general classification:

Estimation by electrical measurements.
Estimation by photochemical methods.
Estimation by photographic methods.
Estimation by fluorescent methods.
Estimation by ionization methods.
Estimation by the selenium cell method.

MEASUREMENT OF VOLUME OF X-RAYS

Estimation by Electrical Measurements.—1. *The Milliammeter.*—Conceding the fact that x-ray volume depends upon two factors—the number of corpuscles striking the target and the volume of the electrical charge given them to carry—it is reasonable to suppose that the number of corpuscles that bombard the target will in turn be governed by the volume of the charge, provided the proper adjustment of the relative number of corpuscles at hand (or the amount of gas available for ionization as indicated by the internal resistance of the tube) be maintained for each variation in current volume. Assuming this to be approximately true, the volume of the discharge delivered to the tube should constitute a fairly reliable, though only approximate index of the volume of x-ray output. To apply this practically, we must further assume that the *milliammeter* is a fairly accurate means of measuring the volume of an induction discharge. This method is, in fact, the only practical means of volumetric estimation in modern *radiographic* work, and although far from being exact, it fortunately serves our purpose fairly well in this connection. Moreover, considering its practicability and approximate accuracy, it is the best method all around that we have for computing the volumetric factor in therapeutic dosage, although it is far from being as accurate as it should be. But the use

of the milliammeter for this purpose is in no way justifiable except when used in *conjunction* with the estimation of tube resistance by the equivalent spark gap method, for the purpose of both proper vacuum adjustment and as an index to penetration. It should always be borne in mind that when heavy charges are used for radiographic purposes, both resistance and penetration increase in direct proportion to any increase in volume of the exciting current; for instance, if a tube shows a resistance equivalent to a 3-inch spark when excited by a current of 2 milliamperes, its resistance will rise in direct ratio with each proportionate increase in the current strength. This combination method of determining volume and of reconciling penetration and volume must always have associated with it one fallacy when used in connection with any *induction* discharge: At each primary interruption the secondary potential and volume, and more particularly the former, rise suddenly from zero to a maximum and then fall again to zero. As far as the milliammeter reading goes, it is in the first place only a record of a certain average of this widely varying current strength of each impulse, and secondly, it indicates only a certain average volume for the continuing series of the impulses, between each of which are two periods—that of the inverse during the make, followed by one of *rest*, which is many times longer in duration than the break period. Moreover, as resistance of tube and penetration of rays rise in a direct ratio with each proportionate increase in current volume, and as increased current volume tends to increase the volume of x-ray output, it follows that this wide fluctuation in current strength must be attended by a certain variation in x-ray volume more or less in proportion, and as a combined effect of these fluctuations of both volume and potential we must expect a somewhat similar variation in penetration of the output. In view of these facts, it would seem that in employing this method we were attempting to compute the value of an extremely complex and variable output of x-ray energy in terms of more or less indefinite average of measurements of widely fluctuating electrical charges. Nevertheless, the latter does serve as a fairly constant and reliable *relative* index of the former, *provided there is associated* with it a properly formed knowledge of effects produced by definite combinations of measurements and certain tube, coil, and other attending conditions. Until a machine is devised that will deliver a *constant* current of uniform potential and strength, and with an output of energy equal to that of the present coil or transformer at least, there can be no way of avoiding this fallacy except in the use of the static machine.

2. *The Strength of the Primary Current.*—It would seem appropriate in this connection to again call attention to the fact that the primary current strength, although once used for the purpose, is not an index of x-ray volume.

Estimation by Photochemical Methods.—The principle of all methods included in this class is the volumetric estimation by comparison of color changes induced in certain chemical substances by x-ray exposure

with the varying shades or tints of standard color scales which indicate the intensity of exposure required to produce the particular shade or tint obtained. They are of service in therapeutic work only.

1. *Holznecht's Chromoradiometer.*—This consists essentially of a color scale and of a capsule supposed to contain a mixture of the sulphate and certain other salts of potassium and copal varnish, the original color of which gradually changes to varying depths of a greenish shade under the influence of radiation. The capsule is placed on the skin of the area exposed, and the intensity of radiation of the part in any instance is indicated by the particular one of the 24 tints, or *Holznecht units,* of the standard color scale which matches that of the exposed capsule.

2. *Sabouraud's Radiometer.*—This is a device somewhat similar in principle to the preceding, but in place of the capsule is used a small wafer upon which is spread a thin layer of barium platinocyanide crystals, which change in color from their characteristic light green to a dirty brown on exposure. As they are susceptible to light and atmospheric changes as well, the wafers must be carefully protected at all times. The method of application is also somewhat different, as when used the wafer is placed in a carrier, not on the skin, but at a definite distance midway between the skin and the anode of the tube. Here, again, a color scale indicates the intensity of radiation.

3. *Bordier's Chromoradiometer.*—This is another similar device. Pastils of barium platinocyanide covered by collodion are placed upon the skin of the exposed area, and intensity is indicated by comparison with a color scale of four shades, which are indicative of the intensity required to induce four definite degrees of skin reaction varying between a simple epilation and a third degree dermatitis.

4. *Freund's Radiometer.*—In this device the color-changing agent is a 2 per cent. solution of iodoform in chloroform. The effect of radiation is the liberation of free iodine, which changes the color to red, and the corresponding shade on the color scale indicates the x-ray intensity required to produce the one of the solution.

It is probably the consensus of opinion among American radiographers, or the majority of them at least, that the inaccuracy of all of these methods, and even the dangers attending their use in some instances, renders definite dependence upon any of them for the purpose of estimating the x-ray intensity factor in dosage unjustifiable. Aside from the possibility of accurately determining the intensity of the complex x-ray output by any method, these particular ones are rendered less dependable through several distinct sources of error, such as, for instance, the factor of personal equation in color comparisons, and the possibility of the color changes taking place without x-ray exposure. Moreover, if they indicate the total intensity of the output they cannot show in any way correctly the proportionate amount of soft ray intensity in the superficial application; or if they indicate only soft ray intensity they are measuring only a portion of the total output.

Estimation by Photographic Methods.—*Kienböck's Quantimeter.*—The active agent in this ingenious device is a strip of bromide paper of standard sensitization, which is placed in a light-proof carrier, transparent to a certain extent to x-rays. After exposure it is developed under standard conditions in respect to developer, temperature, and time. Subsequently, its shade is compared with those of a graduated color scale. The advantage of this method over those previously described is the fact that we are dealing with a more accurate and constant agent capable of standardization, and which ultimately can be used as a permanent record. Otherwise, practically the same, or at least very similar, sources of error must be ascribed to it. This device has recently been improved by the addition of a means of approximate estimation of the intensity of radiation at different depths in the exposed tissues. There is placed over the sensitized paper in the holder an aluminum cover composed of several disks of different thicknesses, somewhat after the principle of the aluminum scale in the Benoist penetrometer. Each increase in thickness is supposed to be capable of the same degree of x-ray absorption as an additional thickness of 1 centimeter of tissue, so that the amount of color change in the corresponding portion of the paper underneath will indicate, so it is claimed, the intensity of radiation of the corresponding depth in centimeters in the tissues exposed. One portion of the strip is left uncovered by the metal in order to show the intensity of radiation at the skin surface.

Fluorescent Methods.—Several methods have been suggested whereby the fluoroscopic screen is employed by the operator, and all of them may be placed in this one group and also classed as too inaccurate, uncertain, and even dangerous, to be of any practical benefit to the operator. The unit of measurement is, in general terms, the distance from the tube at which the intensity of fluorescence of the screen corresponds to that produced by a given specimen of radium or other radio-active substance of a certain standard of radio-activity.

Ionization Methods.—This group includes several methods that have been suggested for using the ionizing property of x-rays as a means of estimating x-ray intensity. So far, none of these methods have been put to practical use, although they are based upon far more rational and scientific principles than most of the methods that have been so far used. In *effect,* the ionization of gases by x-ray impulses is practically the same in many respects as that produced by high potential negative electrical charges, but the process itself is somewhat different, and can be more readily understood, perhaps, if explained in connection with the present theory of x-ray absorption.

As has been previously stated, when an x-ray impulse passes through the molecules of a gas or of any other form of matter, it is supposed that a certain proportion of its energy is used up in accelerating the motions of the corpuscles in the atoms and molecules penetrated. The number of molecules or atoms, irrespective of the physical state of the substance —solid, liquid, or gaseous—that an impulse will *penetrate* depends upon

two things: (1) the amount of energy the impulse has to lose in this way, and (2) the number of corpuscles in each molecule of the substance the impulse traverses, or, in other words, the *atomic weight* of the substance. Or, looking at it from another standpoint, the *absorptive* property of any substance will depend upon the number of corpuscles in the atomic structure of its molecules, or its atomic weight. Hence the relative density of different substances, such as soft tissues and bone, for instance, depends upon the number of corpuscles in a *given volume* of each. Penetration ceases only when the energy of the impulse is exhausted. "Soft" or long impulses, representing less energy, penetrate fewer molecules, and perhaps lose a relatively greater amount of energy in each molecule traversed than "hard," shorter, and more penetrating impulses representing greater energy.

One manifestation of this corpuscular acceleration is the production of *secondary x-rays*, as previously explained, while a second effect upon gases is *ionization*, whereby their electrical conductivity is greatly increased, especially for low potential charges which are not capable of ionization of themselves, as are high voltage induction and static discharges.

The general principle of all the ionization methods is the estimation of the intensity of the x-ray output of any tube by measuring the rate of ionization of air induced by the output of that tube, assuming that a fairly constant ratio exists between rate of ionization and intensity of output. Three general methods have been suggested:

1. *Estimation of the Rate of Ionization by the Electroscope.*—Early in x-ray history, Thomson experimentally demonstrated the fact that the intensity of radiation had more or less influence upon the rapidity with which either positively or negatively electrified bodies, or the electroscope, were discharged. In the methods in which the electroscope is used this instrument is placed at a standard distance from the tube, from which it is protected by a suitable opaque screen with a window and shutter. While the tube is excited the shutter is opened, and the *time in seconds* required for the discharge of the electroscope is the *unit* of measurement of ionization and x-ray intensity.

2. *By the Electrometer.*—The essential principles embodied in the methods in which this instrument is used are diagrammatically shown in Fig. 354. The two poles of the battery B, consisting of a series of cells delivering a current of low voltage, are connected by means of two conducting wires, W, with two flat metal electrodes, C and D. The electrometer E measures any current passing through the circuit. A lead shield, S, cuts off all rays from the tube T except a beam of definite width that is allowed to pass through the window F. When this is open, the beam of rays passes between the electrodes C and D, with the result that the ionized air between them becomes conductive to the current from the battery, and the amount of the latter allowed to pass is measured by the electrometer, the reading of which is the unit of measurement of the rate of ionization.

3. *Dunham and Allen's Method.*—This is a somewhat different method, the essential principles of which are diagrammatically shown in Fig. 355. A beam of rays of definite width is allowed to pass from the tube *T*, placed at a standard distance, through the window *F* of the lead screen *S*, and between the two metal electrodes *C* and *D*, which are connected with the poles of a battery *B*, of a series of cells delivering a

Fig. 354

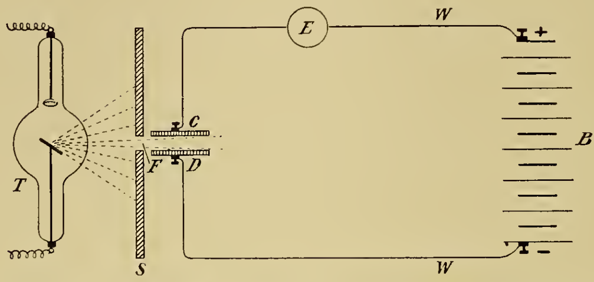


Diagram illustrating the principles of the estimation of the rate of ionization by means of the electrometer.

low voltage current. In this circuit are a grounded electrometer *E*, and two other electrodes *X* and *Y*, of which the latter is a metal box with its bottom covered by a layer of definite thickness of uranium oxide. Furthermore, this box has a sliding metal cover *L*, capable of shutting off the uranium radiations. When the tube is excited, the beam

Fig. 355

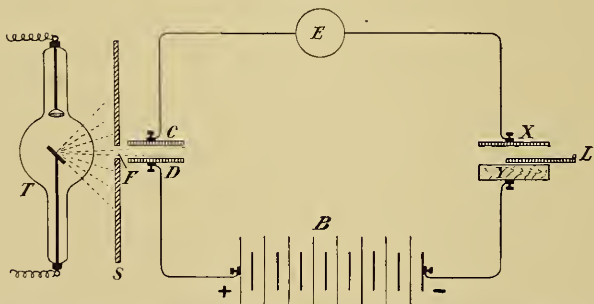


Diagram illustrating the principles of the method suggested by Dunham and Allen for estimating x-ray intensity.

of rays passes through the window *F*, and between the electrodes *C* and *D*, and the electrometer indicates the amount of current allowed to pass over the ionized gap between them. By opening the lid *L*, of the box *Y*, the air between the electrodes *X* and *Y* becomes ionized by the uranium radiations. The lid is then opened cautiously more and more until this ionization is increased sufficiently for the current of opposite

potential from the other pole of the battery to equalize that passing to the electrometer through the gap between C and D, and thereby bring the needle of the instrument to rest. A scale which indicates the extent of surface of uranium oxide uncovered is used as the unit of measurement of the rate of ionization between X and Y, which would equal that between C and D. X-ray intensity is to be calculated in terms of this unit. By placing aluminum or any other suitable metallic screens of standard differences in thickness over the window F, the ionization units may be determined for the different degrees of penetration of the rays constituting the output of any tube.

The one striking fallacy of all of these ionization methods is the employment as a direct or indirect unit of measurement of a necessarily constantly changing effect of a constantly varying output of rays. In order for the measurements to be exact, it is essential that at least three factors directly or indirectly concerned in the rate of ionization be fairly constant, namely, distance, x-ray intensity, and x-ray penetration. The rate of ionization decreases with the distance from the tube, because (1) x-rays are gradually absorbed by the air through which they pass, and (2) x-ray intensity decreases inversely as the square of the distance, or nearly so. This factor can, of course, be made fairly constant, but the distance taken in the measurement of ionization would have to conform with that of the tube from the part of the patient in each instance. Absolute constancy in output, however, implies absolute constancy of secondary amperage and voltage, and of tube resistance, none of which are possible at the present time, at least in connection with induction discharges. Thomson has demonstrated that the rate of ionization is dependent upon the degree of x-ray penetration as well as upon intensity, and as penetration is constantly changing like intensity, exact measurements of the resulting constantly varying rate of ionization would be practically impossible, even though the last method described suggests a way to measure the rate for the rays of each degree of penetration represented in the output.

The Selenium Cell Method.—This depends upon the principle that the exposure of a selenium cell to light reduces its electrical resistance or increases its conductivity. In its application to this method, the cell, in series with a low voltage battery circuit, is placed in a light-tight box in which is also some calcium tungstate. When in use, the box is placed at a standard distance from the x-ray tube. Assuming (1) that the intensity of fluorescence of the calcium tungstate bears a fairly constant ratio to x-ray intensity, and (2) that the resistance of the selenium cell is lowered in proportion to the intensity of light so produced, the unit of measurement from which x-ray intensity is calculated is the ratio between the amount of current allowed to pass in any instance, as shown by a delicate electrometer in the circuit and the amount registered by the instrument before the excitation of the tube. This method has been suggested as a means also of determining the field *of greatest intensity.*

The field of greatest intensity of radiation is a matter to be carefully considered in connection with all methods of volumetric measurement, as well as with both radiographic and therapeutic work. Intensity of radiation is by no means uniform throughout the entire field in front of the plane of the target. In the case of perhaps the majority of tubes there is one portion of this field in which the intensity is fairly uniform and greater than elsewhere, and is the portion between two lines—one 90 degrees to the plane of the target and the other at the same angle to the long axis of the tube and drawn from the target. In some tubes, however, intensity is greatest *immediately around* the line perpendicular to the target, and so much greater than elsewhere that when the tube is placed with its long axis parallel to the plate, the part of the latter corresponding to this portion of the field may be overexposed, while the rest of the plate is normally or even underexposed. This feature of a tube can soon be recognized, and proper allowances made for it, especially by slanting the tube at such an angle that the plane of the target is nearly parallel with that of the plate; or in the case of a radiograph to be made of a part of the body varying considerably in thickness or density, the tube can be placed so that the field of greatest intensity corresponds to the denser or thicker part. In therapeutic work, a dermatitis, when it results, is apt to be more severe in that portion of the skin area corresponding to the field of greatest intensity of radiation.

Meters.—In the earlier period of x-ray work electrical meters were regarded more as conveniences or luxuries than as necessities, but in these days, when greater accuracy is not only possible, but is required and demanded, the specialist, at least, must be equipped with all such instruments as will render his work accurate and efficient to the highest degree possible. At least one electrical meter, the high potential milliammeter, is absolutely essential for any kind of x-ray work at the present day.

Voltmeter.—A voltmeter is a very useful but not a necessary instrument. It is often a convenience in indicating decided drops in voltage such as may be caused on a circuit of limited capacity by sudden heavy demands made thereon, like the running of an electric elevator or the lighting of a large number of lamps rather unexpectedly, as on a dark afternoon. In this way the voltage may be reduced to such an extent as to interfere with the satisfactory operation of a coil. A voltmeter is an instrument that is necessary in connection with the charging and also the use of storage batteries, as the exact potential of their charge must always be known. In the type of battery usually employed, the charge of each cell should be kept between the limits of 1.8 and 2.2 volts, otherwise, more or less injury is likely to result, especially warping of the plates. Voltmeter readings have no direct bearing upon the output of x-rays, and are not, therefore, a factor in the estimation of therapeutic dosage or radiographic exposure. Practically the same dosage may be obtained from a 6-inch portable coil, operated by a 20-volt storage battery as

from a 30-inch coil run on a 110- or a 220-volt current, provided the dosage factors are properly adjusted in each instance.

Voltmeters for measuring the high potential of the discharge delivered to the x-ray tube have not, up to the present writing, been perfected to such an extent as to render them practicable, but it is quite possible that in the near future such an instrument will be devised, and it will then be possible to determine exact measurements of this voltage instead of roughly designating it in terms of spark length, as is usually done at the present time.

Ammeter.—The particular value of an ammeter in the primary circuit is, as has been stated, in connection with the adjustment of interrupters, especially the Wehnelt or the Caldwell instruments. In the case of rapid radiographic exposures requiring heavy primary currents of from 10 to 50 or more amperes in large coils, the ammeter is almost indispensable in properly adjusting the current volume and the interrupter. Although the ammeter reading has no direct bearing upon the length of exposure, and the experienced operator may dispense with its use, nevertheless he is apt to feel greater assurance if he knows the exact volume of primary current he is using.

Until quite recent years a crude practice existed among many Röntgenologists of employing ammeter readings as one of the factors in therapeutic dosage. This practice practically ceased, however, at the advent of the milliammeter. Although the strength of the discharge passing through the x-ray tube may, as will be explained later, be used as one of the essential dosage factors when employed as a means of expressing x-ray intensity, the strength of the *primary* current in a coil does not furnish a correct index of secondary intensity, and is valueless, therefore, in the estimation of the output of the tube. Were all coils and interrupters exactly alike in every respect, and the voltage of the primary always the same, the primary current strength might be so employed, but this is not possible. Aside from differences in coils and voltage, the primary current is, to a great extent, dependent upon the type of interrupter used, and even its adjustment. With the secondary output the same in either case, a much higher current in the primary is required with an electrolytic than with a mechanical spring instrument. When the primary circuit is closed by the interrupter there is a rapid rise in the strength of the current from zero to a certain maximum, and a sudden fall to zero again when the break occurs. Between the break and the subsequent make there is a short period of rest, the duration of which depends upon the interrupter and its adjustment and the rate of interruption, and variations in this rest period especially may have considerable influence upon the ammeter readings which represent a certain average. Moreover, as the maximum energy of the secondary discharge is largely dependent upon this maximum strength of the primary current at the time of the break, there is, perhaps, even a greater amount of variation in the average maximum strength of the

secondary than in that of the primary under such different conditions as those just mentioned.

The High Potential Milliammeter.—This is the one instrument whose use is absolutely essential in all x-ray work. It is a device of comparatively recent production, having been introduced in 1904. Its purpose is to measure the intensity of the secondary discharge passing through the tube. Although the four factors determining therapeutic dosage and radiographic exposure—time, distance, penetration, and x-ray intensity—will be discussed in detail later, it will be necessary to allude to them briefly at this point. Time and distance are the only ones that can be exactly measured and controlled. Penetration and intensity can be only approximately estimated. The milliammeter reading is one of the means employed in the estimation of intensity, and this is the chief use of the instrument. One way of estimating the penetration of the major portion of the x-ray output is by the internal resistance of the tube to the passage of the secondary current, which in turn is expressed in terms of the equivalent spark gap. This method is based upon the fact that a more or less constant relation exists between the internal resistance of the tube and the penetrating qualities of the rays generated, at least that of the major portion, as the output of any tube is made up of rays of different degrees of penetration, but with a preponderance of rays of one degree. The resistance of the tube depends upon the vacuum and the volume of the exciting current.

The use of the milliammeter in estimating x-ray intensity is based upon the fact that a more or less constant relation exists between the strength of the exciting current expressed in milliamperes and the intensity of x-rays produced. A good tube should transform a certain relative proportion of the electrical energy into x-rays, although a very small percentage of that which is delivered is represented in the output, nearly all of it being converted into heat. With such a tube working properly the milliammeter should indicate approximately the amount of energy delivered, and this may be used as an approximate index of the intensity of x-ray production.

This instrument has other practical but less important uses. In the first place, it will indicate any decided or sudden variations in the resistance or vacuum of the tube, which in the case of a drop may mean an undesirable degree of lessened penetration of the rays, or in some instances it may be a warning that the safety of the tube is threatened or that its future usefulness is endangered through lowering of the vacuum to too great an extent. This service of the milliammeter is especially important in radiographic and fluoroscopic work. A sudden and decided drop in the vacuum will be indicated, of course, by a noticeable increase in the milliammeter reading.

The milliammeter registers the volume of only the secondary break discharge, but it will not indicate this exactly unless most of the inverse discharge is eliminated. It may sometimes indicate the presence of a comparatively heavy inverse by not registering the maximum average

volume of the secondary until more resistance is offered toward the suppression of the inverse, for the reason that the latter tends to force the indicator backward. As the instrument will not register if the polarity of the primary and the resulting secondary are reversed, it is desirable to use one equipped with a pole-changing switch.

This instrument is adapted to use on either coil, transformer, or static machine, and its employment is absolutely essential in every instance in which x-rays are used for either diagnosis or for treatment.

CHAPTER XXIX

APPLICATION OF X-RAYS IN X-RAY DIAGNOSIS

THE practical uses to which x-rays may be put is at the present day a subject far too extensive to permit of more than a summary discussion here. The value of the x-ray impulse lies in the effect it is capable of producing in certain forms of matter, those of the latter in which we are especially interested being the tissues of the body, the silver salts in the film of the x-ray plate, and the fluorescent substances used in the fluoroscopic screen. So far as our present knowledge goes, we might trace the origin of these effects ultimately to the action of the impulse upon the corpuscular structure of the atom, which is supposedly an acceleration of the corpuscular motion, attended by a gradual loss and ultimate complete absorption of the energy of the impulse.

Three general methods are employed in x-ray diagnosis—the *radiographic,* the *stereoradiographic,* and the *fluoroscopic,* and to these might be added certain modifications of one or the other, such as *exact localization* and the use of the *orthodiagraph.*

RADIOGRAPHIC METHOD

The radiographic method depends primarily upon the effect produced by the impulse upon the corpuscular structure of the atoms of the silver salt in the sensitized film of the plate, whereby a certain molecular, or perhaps atomic change is induced which is somewhat similar to that caused by exposure to light. Secondly, the method depends upon the different degrees of *density* to x-ray penetration of different substances or tissues, or the differences in their capacities for absorbing x-ray impulses. These differences are supposedly due, as previously explained in connection with the process of ionization, to numerical variations in corpuscular elements which are responsible for the identities of all forms of matter. As a result of this property of absorption, tissues or objects are capable of obstructing or absorbing rays of a given degree of penetration in proportion to their densities. The effect of the rays reaching the plate upon the silver salts of the different portions of the film will, theoretically at least, be proportionate to the intensity of the radiation to which the respective portions are exposed, hence all tissues or objects interposed between the tube and plate will be represented on the latter by shadows, so to speak, the relative densities of which will be proportionate to the relative densities of whatever they represent.

This explains the origin of the term *skiagraph,* which is synonymous with *radiograph.*

Any structure of the body is capable of producing a distinguishable radiographic shadow, provided its density to rays differs sufficiently from that of the surrounding structures, and provided, of course, the rays are of a suitable degree of penetration. In the early days of long exposures and when little was known of means of determining or controlling x-ray penetration or intensity, little more was obtainable or expected in the way of tissue differentiation than that between bone or foreign bodies and soft tissues. But in these days of short exposures and improved apparatus and means of approximately determining and controlling intensity and penetration, remarkable differentiation is possible. In dense structures like bone, lesions can be detected just as soon as sufficient alteration in structure occurs to materially change the density of the area affected; and in the case of soft tissues we are able to demonstrate pulmonary lesions, for example, at the very earliest stage of the process, and often even before physical signs are manifest. Much still remains to be accomplished, however, such as the certain diagnosis of biliary calculus, for instance.

The important factors to be considered in making a satisfactory radiograph are the *penetration* of the rays, the *intensity* of radiation, and the *development* of the plate. The essential factors in rendering the diagnosis are the production of a *satisfactory radiograph* and its *correct interpretation.*

Penetration.—This factor has already been considered, and little more remains to be said concerning it. Too much emphasis cannot be given to the fact that the best details of tissues are obtained by using the softest tube and rays consistent with the density of tissues and thickness of the part examined. Too hard a tube yields flat pictures, because rays of too great a degree of penetration pass too readily through the denser structures, such as bone, as well as through the soft structures; while too soft a tube, on the other hand, gives no picture at all, because no tissues, except possibly the soft structures, are penetrated. As there is so much difference between the densities of soft tissues and bone, and because of the relatively slight density of the former, reasonably wide variations in x-ray intensity and penetration do not preclude the possibility of fairly satisfactory radiographs in many instances, hence the unskilled and inexperienced operator may render fairly efficient service if his work is confined to examinations of the bones of the extremities of ordinary thickness; but beyond these limits, and especially in the more difficult work, such as the examination of the lungs and kidneys, his efforts yield either poor results or none at all.

Exposure.—As the effect upon the sensitized film must be more or less in proportion to the intensity or volume of the rays reaching it, the factors governing the length of exposure must be tissue density and thickness and x-ray penetration, on the one hand and, on the other,

those factors upon which volume directly depends—time, distance, and x-ray intensity.

It is always essential to consider carefully the density of the tissues and the thickness of the part in estimating the length of exposure to be made. Lung tissue, being the least dense of all the structures of the body, is the easiest to overexpose. A normally exposed plate of the chest itself or of the heart and vessels, even though it may be a beautiful radiograph of these structures, is likely to be overexposed and useless so far as the lung structure is concerned; and, on the other hand, the best lung pictures are often far from being good chest pictures. In individuals of ordinary size, radiographs of the chest, as a rule, require less exposure than most other parts of the body, because of the slight resistance offered by the lungs, especially as compared with the relatively far greater density of the other intrathoracic viscera.

Penetration more directly concerns tissue density than it does the length of exposure, but it may have some direct bearing upon the latter. Very few of the x-ray impulses that reach the plate are absorbed in the film, but it would seem reasonable to suppose that the action upon the silver salts of soft rays just able to penetrate the part exposed would be more intense than would that of harder rays. If this be true, it is still another reason for using the softest tube and rays consistent with tissue density and thickness.

Time is the most variable factor, because it is more or less dependent upon all of the others. It is the co-efficient of intensity and volume. It must be governed by distance, because intensity decreases inversely as the square of the distance of the plate from the anode. Short exposures are, as a rule, preferable to long ones, for, in the first place, it is an undeniable fact that the shorter the exposure the clearer and greater the details and the better and more comprehensive the picture. One important explanation for this, in the case of radiographs of the extremities at least, is the fact that short exposures minimize the very slight, yet appreciable blurring effect of imperceptible and unconscious muscular movements and certain slight motion due to the pulsation of the vessels of the part. Another advantage of rapidity is to be noted in the success recently attained in the diagnosis of early pulmonary lesions through the avoidance of the effects of the pulsations of the heart and great vessels.

The avoidance of respiratory movement is essential for accuracy in examinations of all abdominal viscera, and, in fact, of all other portions of the body likely to be affected by breathing, such as the neck and shoulders. In examinations of the stomach there is additional need of rapidity in avoiding the blurring effect of excessive peristaltic action, and in order to catch a peristaltic wave the exposure should not be over one or two seconds at the most.

Quick exposures are, of course, indispensable in the examinations of restless children and infants who cannot be kept quiet for even a few seconds.

The exposure tables often seen in print are absolutely worthless, as

anyone will realize in considering the fact that any exposure depends upon such a variety of factors and conditions as the coil, the current, the interrupter, the resistance, and other conditions of the tube, the rapidity of the plate used, the developer, and the thickness and the density of the part examined. Experience is the only satisfactory exposure table.

It happens occasionally with the best apparatus, and quite often in the case of inferior equipment, that satisfactory radiographs cannot be obtained because of the unusual size of the individual examined, or some such reason. It is now possible under such conditions to obtain a more or less satisfactory picture through the use of an *intensifying screen,* which is an unmounted fluoroscopic screen placed in the envelope or plate holder with the plate. It utilizes some of the waste *x*-ray energy that has passed through the film. The silver salts are not very susceptible to the color produced by platinocyanide screens, however, hence the action is very slight, and as the light from them is more or less diffused, the resulting details are not clear, but the recently introduced calcium tungstate screens have proved very satisfactory.

The Development of X-ray Plates.—While the process is the same in principle, the method of developing *x*-ray negatives differs from that of photographic plates in many essential details, and unless the ordinary photographer has acquired experience in radiographic work, he should not be intrusted with the development of the more difficult *x*-ray negatives. Far more important than the development, however, is the part of the work done outside of the dark room in properly exposing the plate. No process of developing nor any amount of skill in the dark room can produce satisfactory radiographs from improperly exposed plates. The range through which errors in exposure can be corrected by methods of development is very limited. The examiner is the person best informed concerning the various conditions attending the exposure of the plate, as well as all the features of the case, the part, and the condition examined, and the exact information that is desired from the radiograph; hence he is the one best qualified to develop the plates, and especially the more important and difficult ones.

The essential differences in the development of *x*-ray and photographic plates, and the factors upon which the differences depend may be stated as follows:

1. All arise primarily from differences in the action of light and *x*-rays upon the silver salts. Not only is the action of the *x*-rays less intense than that of light, but the effect upon the molecular or atomic structure of the silver salts is probably somewhat different also. At any rate, as a result of some difference, the *x*-ray negative requires a more concentrated developing agent, more alkali, and a proportionately larger amount of bromide restrainer to prevent overaction, overdevelopment, and chemical fog. The temperature factor is also very important.

2. The first requisite in the radiograph is *detail,* and the second is the greatest amount of *contrast* possible with the minimum sacrifice of

detail. Hence such developing agents should be used as are best adapted to meet these requirements.

3. Many negatives, and usually very important ones, must of necessity be considerably underexposed at the best, but, nevertheless, they must be made to yield the greatest amount of information possible, and cannot be discarded as photographic negatives of like degrees of underexposure would be.

4. The emulsions of many x-ray plates are spread considerably thicker than those of the ordinary photographic plates, and the former, therefore, require more thorough washing after development, longer fixing, and more prolonged final washing.

5. X-ray plates are usually more sensitive to light than are those used for most other purposes, and not only would they be fogged by an amount of dark-room light reasonably safe for the latter, but they should not be *directly* exposed to any dark-room light whatever, until after development is well advanced, and even then for a few seconds only. Moreover, x-ray plates should never be taken out of the developer for examination or any other purpose until ready for fixing.

6. As no paper that is suitable for the purpose is free from harmful chemicals nor absolutely opaque to light, x-ray plates should not be placed in their envelopes until ready for use.

The two essential factors in the radiographic diagnosis—a satisfactory radiograph and its correct interpretation—are of equal importance, for the reason that one is practically useless without the other. A satisfactory *diagnostic* radiograph must be satisfactory from the diagnostic standpoint, though it may not necessarily be so from the artistic standpoint. This implies efficient apparatus and its proper manipulation, and the proper development of the plate, on the one hand, and, on the other, an adequate knowledge of clinical data concerning the case examined, a thorough comprehension of the condition suspected or for which the examination is made, and a suitable knowledge of human anatomy.

The apparatus is an important factor in governing the scope of radiographic diagnosis. New achievements in a large measure depend upon the wider possibilities afforded by improvements in apparatus. Needless to say, the beginner's accomplishments will be limited by his experience, especially in the more difficult work, but no examiner need attempt work of a more difficult character than his apparatus is capable of accomplishing. An equipment suitable for only such simple work as examinations of fractures of the extremities is certainly not capable of fulfilling the requirements of *general* diagnostic work.

Special Apparatus.—In addition to the strictly essential parts of the equipment—the coil and tube—certain special devices are needed to make the equipment complete for general work, and in order to insure the greatest precision and accuracy, as well as for convenience. The more important of the accessories needed are the following:

1. A *radiographic table*, fitted with diaphragms, the purpose of which has been explained, and with a *compression device*, in the form of either rings, cylinders, or flexible bands of some fabric, for the purpose of holding the patient or the part still and of making compression, such as is necessary, for example, in radiographing the abdomens of stout subjects.

2. A portable tube stand, also fitted with diaphragms, is indispensable, especially in hospitals where many patients must be examined in bed.

3. *Tube shields* should be employed in all instances, in order to protect both patient and operator from needless exposure, and the patient, in addition, from any dangers attending the possible collapse of a tube, as well as to hold the tube. They should be made of a material that is capable of protection, and should enclose as much of the tube as possible. The thin, flexible rubber or other composition shields that are still on the market are a delusion and a snare, and are utterly worthless. Heavy lead glass makes, perhaps, the safest and most serviceable shield of all the materials used at the present time, but even it does not afford absolute protection by any means.

4. As many examinations must be made with the patient in the erect posture, some suitable appliance must be provided for this purpose. Other important devices, such as stereoscopic apparatus, fluoroscopes, intensifying screens, orthodiagraph, and special localization apparatus, if not already described, will be considered subsequently. There are many other useful but less essential appliances, such as view boxes for examining plates, and time switches, for example, but which do not need to be considered here.

It is necessary that the examiner should have some definite previous knowledge as to what one or more possible conditions are present and for which the examination is to be made, hence adequate clinical data concerning each case are essential for accurate results. A reasonable comprehensive clinical and pathological knowledge of every condition for which an examination is made, and a thorough anatomical knowledge of the structures and their relations in every part examined are also essential on the part of the examiner.

Interpretation of Radiograph.—The correct interpretation of the radiograph may in perhaps the majority of all instances be readily and correctly rendered by the clinician, or by anyone who is more or less familiar with radiographic appearances and human anatomy; but this applies only to the ordinary routine examinations, such as for fractures and the like, and not to the more difficult and complicated diagnostic work, in which accuracy depends upon adequate clinical data, general clinical, pathological, and anatomical knowledge, and, above all, experience. Adequate clinical data and an adequate knowledge of the clinical and pathological features of the condition or conditions suspected or found are absolutely essential in many instances, either to enable the examiner to form the proper basis for his interpretations, or in order that he may be able to distinguish between certain conditions which present

similar radiographic appearances, such as, for example, a quiescent from an active process in tuberculous epiphysitis or arthritis, or other bone or joint lesions; active tuberculous foci in the lungs from scars and healed lesions; tuberculous consolidations from infiltrations or filled abscess cavities; sarcoma from a syphilitic bone lesion; phleboliths or calcified glands from ureteral calculi, and many others. A thorough anatomical knowledge alone, as applied to radiographic appearances, and especially the normal appearances of all parts of the body, is frequently indispensable. For example, a knowledge of epiphyseal ossification and union and the radiographic appearances of the joints of children at different ages is essential in connection with injuries and diseases at or near the joints in children; without a knowledge of the proper positions and relations of the kidney or the stomach, it is impossible to accurately determine certain abnormalities in these organs; and the same may be said in connection with the heart and the great vessels.

Experience is, perhaps, the most important factor in correct interpretation, and without it the attempt to interpret the appearances in many of the more difficult radiographs is more or less guesswork. In view of all of these requirements, the experienced radiographer is the one best qualified to interpret his own plates correctly, and as the experienced clinician cannot be an expert in radiography as well, he must rely upon the interpretation of the x-ray examiner entirely in a great many instances. Therefore, whenever the expert opinion of the radiographer is required or requested, the examination, as a whole, should be regarded as a *consultation.*

The attempt to interpret from a plate more than it will show with certainty borders on guesswork. Too much should not be expected of the radiograph nor too much reliance placed upon it in connection with certain conditions in which the x-ray examination is either not uniformly dependable or is rarely to be relied upon for diagnosis, as, for example, diseases or injuries of cartilage, acute epiphysitis, acute bone or joint diseases during the early stages, biliary calculus, brain tumors, etc. Under certain circumstances an x-ray diagnosis should be made more or less conditional, as in the case of a possible epiphyseal separation without fracture that may have been previously reduced, or such an injury before the age at which ossification begins, or in urinary calculus in very stout individuals.

Precautions.—There are certain precautionary measures that should be carefully observed in connection with every x-ray examination, or with certain special ones. Improved technique and modern equipment have rendered the danger from dermatitis very slight at the present day, but still all precautions should be taken against its occurrence. Cases of acute pneumonia should not be subjected to x-ray examinations unless such an examination is imperative. In gastro-intestinal or other examinations, in which large amounts of bismuth are required, either by injection or internal administration, the dangers from the two types of poisoning—nitrite intoxication from the use of the subnitrate, or the

true bismuth poisoning—should always be borne in mind. In the examinations of fractures or other injuries, dressings should not be removed without the consent of the attending physician or surgeon, but when their removal is necessary this consent should be requested. It is wise to avoid examining cases not referred directly by a physician or surgeon or by an institution, but whenever it is done, the examiner should be careful to ascertain the exact reason for which the examination is desired, as otherwise he may frequently become involved in disagreeable medicolegal procedures. An excellent safeguard against many unpleasant occurrences is to make it a rule never to give or show plates or prints to patients or to anyone else except the medical attendants referring the case, without the consent of the latter.

STEREORADIOGRAPHIC METHOD.

This is practically an adaptation of many of the essential principles of stereoscopy to radiography. Its particular advantages arise from the fact that instead of the visual impression conveyed by the simple radiograph of a number of shadows of different densities superimposed in the one plane of the single plate, and having but two dimensions, the same shadows in the two stereoscopic plates seem to acquire the third dimension and to be given perspective. It is necessary in such examinations to make two separate radiographs of the part from slightly different angles, but with the two plates and the part of the patient in exactly the same position in each exposure. A special plate holder is required, and after the first plate is exposed it is removed and replaced by a fresh one, either by hand or automatically, and the tube is moved through a plane exactly parallel with the plates, a distance of about $2\frac{3}{4}$ inches, or the eye distance, after which the second exposure is made. The distance of the anode from the plates should be measured and recorded for future use. The two radiographs must be examined by means of special apparatus corresponding in principle to the ordinary types of stereoscopes.

Apparatus.—There are two general methods and types of apparatus employed for this purpose:

1. *The refracting stereoscope* resembles the ordinary hand stereoscope used for looking at stereoscopic views. The two plates are placed side by side in front of a radiographic view box, and viewed from the proper distance through two prisms, which are mounted either in a separate hand appliance or as a part of the examining apparatus. The prisms themselves and their distance from the plates should be adjusted until the two negatives are seen as one and the stereoscopic effect is obtained. For convenience, the two plates may be reduced to a suitable size and mounted together for use in the ordinary hand stereoscope.

2. *The Wheatstone reflecting stereoscope* is, perhaps, the more popular type, at least in this country. The principles of its construction and use

are diagrammatically shown in Fig. 356. The two negatives *P, P*, are placed in front of the light boxes *L, L*, which are movable in either direction to right or left. They should be adjusted so that the two plates are equidistant from the middle of the instrument, or the angle *C* made by the two reflecting mirrors *M*. The best stereoscopic effect will be obtained by adjusting the boxes so that the distance from the observer's eye *E* to that portion of the mirror *X* upon which he gazes, plus the distance from *X* to the negative, is about the same as was the target of the tube from the plates when the exposures were made. Under these conditions the tube should be moved $2\frac{3}{4}$ inches, or the proper stereoscopic angle. If the tube distance cannot, for any reason, be made the same as that of *EX* plus *XP*, the tube should be moved the distance which would make the same angle *if it were* that far from the plate. With the plates adjusted at the proper distance, the observer looks directly ahead at their reflections in the two mirrors, which are placed

Fig. 356

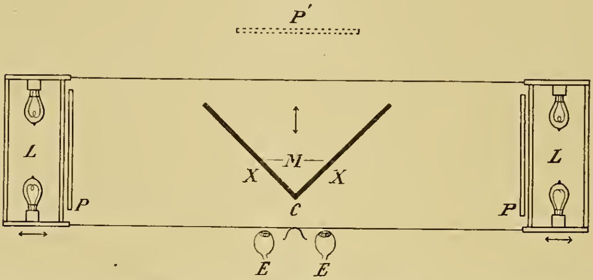


Diagram illustrating the principles of the Wheatstone stereoscope for examining stereoradiographs. (Plan.)

at an angle of 90 degrees to each other, and should see but one stereoscopic image *P′*, which should present the proper stereoscopic effect. If this is not obtained, the mirrors should be moved either toward or away from the eyes until the proper effect is observed. For this purpose the mirrors are mounted on a movable stage.

Advantages.—The advantage of the stereoscopic examination, in general, is the fact that one is able to identify every one of the shadows on the plates with the structure it represents, as well as to obtain an accurate conception of the relative dimensions, relations, and location of each structure thus shown. It is not practicable as a routine method, on account of the very considerable increase in expense, labor, and time entailed, and the inconvenience attending the examination of the plates, and although its employment is not advantageous in the vast majority of instances, there are many examinations in which it possesses a most decided advantage, such as the following:

Diagnostic Uses.—*Head.*—In the examination of sinuses, particularly the sphenoid and posterior ethmoid, where it is indispensable; the majority of growths of any part, but especially in the orbit, sinuses, antra, and

various fossæ, and intracranial tumors, abscesses, or cysts; fractures of the skull, especially of the base, face, and orbit; mastoid disease; and in the location of foreign bodies in some instances. It is practically the only method applicable in the localization of foreign bodies in the orbit in case of collapse or great swelling of the eyeball, when the ordinary special localization apparatus cannot be used.

Chest.—In many respects, its employment in chest examinations is a new departure, especially in the examination of the lungs and mediastinum. It promises to become exceedingly valuable in the detection of incipient tuberculous foci, as well as in showing their exact location, and it will no doubt prove to be most useful in identifying the many doubtful and confusing shadows representing structures either normal or abnormal in the regions of the roots of the lungs. It is already very useful in the localization of foreign bodies in the chest.

Urinary Calculus.—A stereoscopic examination is frequently advantageous, when practicable, in properly identifying doubtful shadows, such as those of phleboliths, calcified glands, etc., either with or without catheterization of the ureters.

Foreign Bodies.—This method is frequently superior to any other in the exact localization of a foreign body, especially in the case of needles in the hands or feet, as it shows the exact direction in which such bodies lie, which cannot be done by any other means. In such cases it is advantageous to rub some bismuth powder over the skin in order to bring out the skin surface distinctly in the plates.

Bones and Joints.—A stereoscopic examination is occasionally of decided value in connection with a fracture or dislocation, two noteworthy examples of the latter being shoulder and subastragaloid dislocations. It may, likewise, often be found desirable in the diagnosis, localization, and determination of the exact nature of lesions in bone disease.

Spine.—Single radiographs of the spine are comparatively unsatisfactory for the detection of injuries of a minor grade, or early pathological processes, because of the confusing superimposition of shadows resulting from the complex structure of the vertebræ. In many instances, however, a stereoscopic examination, if practicable, will show distinctly an abnormality that is not in the least way suggested in the ordinary radiograph.

Special Methods for Exact Localization of Foreign Bodies.—These may all be classed under three general methods—stereoscopic localization, which has just been alluded to, the simple method by two radiographs made in two directions at right angles, and the use of various special localization devices. The second method is, of course, the simplest and easiest, but is not always practicable, satisfactory, or sufficiently accurate or exact. It is unnecessary to go into any details in connection with the principles, the construction, or the use of any of the special localization instruments. The same essential principles are embodied in all, and one can readily obtain explicit directions for the manipula-

tion of any form of localizer he may purchase. The highest state of perfection of the localization device in ingenuity and simplicity of construction, ease of manipulation, and marvellous accuracy of the results attainable is exemplified in the instruments for the localization of foreign bodies in the eye and orbit. For the attainment of such perfection we are in a great measure indebted to Dr. Sweet, of Philadelphia. Such instruments as his can now be depended upon to localize with absolute accuracy any foreign body sufficiently dense to project a shadow.

THE FLUOROSCOPE

It is unfortunate, when having at our command such a simple and ready means of direct examination as the fluoroscope, that its range of application should be materially restricted because of its use being attended with so much risk to the examiner who is constantly engaged in x-ray work. Indeed, with very many radiographers, this instrument has fallen into such disrepute as to have led to its absolute abandonment. In stating the true merits of the fluoroscope from a conservative standpoint, many facts must be considered. On the one hand, we must duly consider the risks attending its use, and also give due consideration to the opinions of those who for perfectly justifiable reasons refuse to use it. On the other hand, we must concede the many unique advantages of this direct method of examination; we must consider the fact that it is still extensively employed, especially abroad; that the attending risks may be very materially lessened by the strict observance of proper precautions; and that its occasional employment with reasonable care by those not actively engaged in x-ray work is probably not harmful.

Because the use of the fluoroscope brings the examiner closer to the source of radiation than does any other procedure, it is reasonable to regard it as the most active factor in the production of those most unfortunate results that have caused the deaths of such a large number of the older x-ray workers, the loss of fingers, hands, and even arms of many more who are still living, and the untold suffering, the permanent disfigurement, and various other dire effects among the number who condemn the use of this most active cause of their troubles. However active a factor the fluoroscope has been in the causation of these misfortunes, careless and unnecessary use of the instrument and lack of adequate or even any protection have undoubtedly been the largest contributing factors in almost every instance.

Absolute protection to the examiner in connection with any fluoroscopic method of examination means the absolute avoidance of any exposure to x-rays of any kind, direct, indirect, or secondary, and this is impossible without the use of very costly and complicated protecting devices, in which it is imperative that the fluoroscopic picture be reflected by a mirror, and not observed directly. The question of the chance of

ultimate harm being sufficiently minimized through the employment of less expensive, less complicated, and less unwieldy and cumbersome protecting devices, affording a fair amount of protection and permitting direct observation of the screen, is one that must be decided by the individual entirely upon his own responsibility. Moreover, no one has the moral right to expect another to use a means of diagnosis such as the fluoroscope when its employment is objected to because of the acknowledged risks entailed. Nor is it the evident evil effect shown in past results that should alone be considered, for upon these very evident comparatively quick results it is justifiable to base an opinion that others equally serious may possibly become manifest after many years of cumulative action produced by comparatively very mild but continuous exposure.

Too much emphasis cannot be laid upon the warning against engaging in routine fluoroscopic work without adequate protection, and the wearing of gloves and aprons is *not* adequate, but very *inadequate.* Certainly this method should not be employed unnecessarily. Finally, the safety of the patient should never be forgotten.

Advantages.—The fluoroscope possesses the one general advantage of being the only means of direct examination. While it is by no means uniformly applicable, there are certain instances in which it may be employed to some advantage, such as the following:

Diagnostic Uses.—*Foreign Bodies.*—Its simplicity renders this method a very convenient means of determining the presence or absence of *certain* foreign bodies in *some instances,* but it is not often sufficiently efficient in their localization. The fluoroscope is especially valuable in this connection in warfare. It is occasionally of assistance to the surgeon in the *removal* of bodies such as needles.

The Chest.—The fluoroscope is the only means whereby the pulsations of the heart and vessels and the movements of the diaphragm may be observed, and deglutition studied. In all other instances, aside from the applications of the orthodiagraph, it is of no service, and at the present time should not be directly depended upon for diagnosis.

Gastro-intestinal Tract.—In the study of peristaltic movements and their effects, as well as those of certain forms of obstruction upon the progress of certain opaque substances, such as bismuth, when introduced into the stomach or large bowel, the fluoroscope has been the means of obtaining much valuable information, from the standpoint of experimental physiology as well as in diagnosis.

Fractures and Dislocations.—Absolute dependence upon the fluoroscope for the *diagnosis* of fractures or dislocations is unjustifiable except in rare instances. It is often of great assistance, however, in the reduction of some fractures that are especially prone to resist replacement.

Disadvantages.—Its disadvantages, in addition to those already mentioned as the dangers to patient and operator, are, its inaccuracy, especially in inexperienced hands; the fact that the examiner is the only individual permitted to see the condition and render the diagnosis;

and that it does not furnish a permanent record of the examination as does the radiograph.

Care of the Fluoroscope.—Unless properly cared for, most fluoroscopes, and especially those in which barium platinocyanide is the fluorescent substance, will deteriorate. As x-ray exposure, sunlight, and a dry atmosphere are the active factors in this deterioration, the dark room is an excellent place in which to keep a fluoroscope when it is not in use.

Technique.—In fluoroscopy, as in radiography; penetration is an essential factor, and for similar reasons. If it be too weak, the screen will not be properly illuminated, while if too great, the denser structures will be nearly as readily penetrated as those less dense, and there will be insufficient contrast between the shadows on the screen. X-ray volume is of importance only in so far as there is sufficient illumination of the screen, hence much less current is needed to excite the tube as compared with what is required for rapid radiographic work. This being the case, and as fluoroscopic examinations are apt to be prolonged, the tube should be operated by as little current as possible, first, to prevent excessive heating, which, if it may not happen to crack the tube, may lower the vacuum too much and decrease the penetration; and secondly, in order to minimize the risk to the patient of a dermatitis by exposing him to the least possible volume of radiation.

Orthodiagraph.—This may be regarded as merely a special adaptation of the fluoroscope in an appliance for diagrammatically outlining the shadows of various structures in such a manner that the dimensions and relations of the outlines are exactly the same as those of the structures they represent. In other words, in addition to the fluoroscope, the device embodies a means of correcting the errors arising from distortion and projection. Under all conditions, x-ray shadows are more or less magnified or distorted, because the rays emanate and diverge from one point, and the magnification of the shadows increases directly as the distance of the object or structure from the screen or plate, and is further increased by closer approximation of the tube.

In the orthodiagraph, a jointed frame passing around the patient on one side holds the tube at its distal extremity, while that nearest the examiner, and on the near side of the patient, supports a fluoroscopic screen and a stylus or pencil. This frame is so mounted that it may be moved as a whole in almost any direction, while it is rigid itself, and is so constructed that the pencil *always points directly toward the anode* of the tube. The fluoroscopic screen is so attached to the frame by a separate rod that it may be moved in any direction in a plane perpendicular to a line from the pencil to the anode of the tube. The stylus or pencil projects through an opening in the screen, so that it can be made to record outlines either on the patient's skin or on a card held in a frame between the patient and the screen. In drawing the outline of the shadow of any structure, the pencil must, of course, be moved to the edge of the shadow shown on the screen, and in so doing, the anode of the tube must be brought directly opposite the pencil, which

relation it maintains throughout the whole procedure of outlining the shadow. In this way the anode, pencil, portion of the outline of the shadow drawn, and the corresponding point on the edge of the structure are always in the same straight line, hence the outline drawn represents the exact dimensions of a cross-section of the organ, such as the heart, in the plane perpendicular to the line of vision. Although several different forms of this instrument have been devised, all of them embody this principle.

The orthodiagraph is of special value as a means of making and recording accurate heart measurements. It is also useful for the purpose of outlining the stomach and colon, and may be employed as a means of localization of foreign bodies. For the latter purpose the outline of the shadow of the body is drawn with the tube and frame stationary, using a separate pencil. Then the exact outline of the body is drawn by the orthodiagraphic method. Knowing the distance of the tube from the screen, the exact size of the body, and the size of its ordinary shadow, its depth below the surface of the skin or its distance from the fluoroscopic screen may be readily calculated.

CHAPTER XXX

X-RAY THERAPY

In the case of many of our useful therapeutic agents, their use has been first suggested through the observance of their physiological action upon healthy tissues, either directly or indirectly produced, and it is not surprising, therefore, that the first instance of a typical manifestation of such an action induced by x-ray exposure should have first suggested the possibility of x-rays possessing therapeutic properties. The first experimental applications were made in 1896 by Freund, who, after having observed one of the earliest cases of an accidental x-ray dermatitis, and which was attended with a loss of the hair, realized the possibility of practical use being made of this undesirable effect in the attempt to remove the hair from a large pigmented nevus. He was unsuccessful, however, but in subsequent experiments he met with better success in connection with lupus vulgaris, and in 1897 he and Kümmel each reported a case of this condition cured, these being the first cures by x-ray treatment reported. Since that time, x-ray therapy has passed through a long experimental stage, which has been attended by a more or less indiscriminate use of this agent. At the present time, however, the true value of x-ray therapy is well recognized, and its use has gradually assumed a rational and conservative basis.

Physiological Action.—This forms the real basis for x-ray therapy, and an adequate understanding of physiological effects is one of the essential qualifications for the successful practice of Röntgen therapy. In view of our theoretical knowledge concerning the process of absorption of x-ray energy by matter, and the effects thereby induced in the atomic structure, as a result of which such phenomena are manifest as the rearrangement of the atomic structure of the silver salt in the film of the photographic plate, the ionization of gases, and the production of secondary radiation, one can readily realize how alterations in the metabolic and vital processes are likely to result from similar effects upon such complex molecular and atomic structures as those of cell protoplasm.

The gross manifestations of the effects of the radiation of tissues, or the reactions of the latter, are either *stimulation, irritation* (inflammation), or *destruction*. The particular reaction produced depends primarily upon the amount of radiation, and secondarily, to a greater or less extent, upon the vitality, the stage of comparative embryonal development, or the degree of specialization of the cells, on the one hand, and a certain selective action of the rays on the other. The effects of radiation upon tissues will be considered in further detail in connection with the dangers attending the use of x-rays.

Principles of Treatment.—The therapeutic properties of x-rays depend upon their ability to produce different reactions in the tissues treated and their selective action for certain cells. The therapeutic effect necessary to bring about the desired result in any case depends upon the production of the appropriate tissue reaction. There are certain cardinal principles upon which successful x-ray treatment is based, and in addition to such requisites as a reasonable amount of experience, an adequate proficiency in the manipulation of apparatus, and a knowledge of the nature and pathology of the condition treated.

1. Success depends upon a knowledge of the reaction required to produce the desired result in any case, whether it be stimulation, irritation, or destruction, or all three; and secondly, upon the administration of the dosage necessary to induce that reaction.

2. In considering selective action from the standpoint of comparatively *healthy* tissues, the direct effect of radiation upon cells is manifest to a certain extent in the order of their specialization. This is especially the case in connection with the epithelial elements of the skin, those lining the glands and follicles showing a quicker and more decided reaction than any of the other cells. The production of sterility is another good example. In the case of *diseased* tissues, the effects on the cells are manifest largely in the order of their vitality, and also to a certain extent in the order of their approach to the embryonal types in retrograde stages of development, as, for example, in the case of malignant growths.

3. The effect of repeated exposures is cumulative, when the applications are not made too far apart. The reaction induced by one *massive* dose is quicker and more intense than that produced by several short repeated applications of equal dosage value.

4. The effect of radiation is most intense in the tissues in which the x-rays are absorbed.

5. X-rays possess practically no direct bactericidal properties in connection with pathogenic bacteria either in culture media or in the tissues, and the destruction of the organisms in tissues is always a secondary result of the tissue reaction. Any of the three tissue reactions may be *favorable* to the vitality of the *pyogenic* organisms.

The quantitative value of a *therapeutic dose* implies the quantity of radiation applied. Strictly speaking, *quantity* of radiation is the product of intensity and time, but in connection with dosage we may regard it as a combination of several variable factors—intensity, penetration, time, and distance. *Penetration* has already received ample consideration. *Intensity* implies the rate of delivery of radiation, and has, likewise, been considered elsewhere. *Time* is the most exact factor and the one most readily adjusted to conform with variations in intensity, penetration, and distance in the estimation and administration of definite dosage values.

Distance should always be measured between the target and the surface of the part treated, and it should always be borne in mind that intensity decreases practically in inverse proportion to the square of

the increase in distance. The closer the tube, the greater the intensity of the radiation of the part and the greater the effect produced, either on the skin surface or in the deeper tissues. In the treatment of superficial lesions, it is best to place the tube *close* to the surface, as a quicker skin reaction is thereby induced, and with the minimum effect on the deeper structures. In making deeper applications, however, it is better to place the tube farther away, making the proper time allowance for the increased distance. A little mathematical calculation will readily show that as the tube is moved away the effect diminishes more rapidly upon the skin than on the deeper tissues, especially at first.

Protection of the Patient.—The possible sources of danger to the patient should always be borne in mind, and all reasonable precautions taken for their avoidance. All parts not to be included in the exposure should be carefully protected. This applies especially to the eyes, skin of the face, the scalp, and the testicles. Mucocutaneous junctions are especially susceptible, as is also the skin in regions where it is subjected to constant moisture or friction. Suitable tube shields and diaphragms are essential, and where small areas are treated additional protection by sheet lead or foil should be employed. Patients should always be previously warned of any unavoidable risks. In the treatment of deep lesions the use of *x*-ray filters is advisable.

SPECIAL APPLICATIONS

X-ray therapy is too extensive a subject to permit of any detailed consideration here, and only a brief résumé of its more important applications and the average results to be expected will be given.

Dermatology.—The *x*-ray is now recognized as a valuable and almost indispensable addition to the list of *local* therapeutic agents employed by the dermatologist. The accompanying table (see opposite page) indicates its more important applications.

Tuberculosis.—The benefit to be derived *directly* from *x*-ray treatment in any tuberculous lesion depends solely upon the production of a reaction in the tissues which, on the one hand, is unfavorable to the vitality of the tubercle bacillus, and, on the other hand, promotes the process of healing in the affected area. The effect in general of the amount of radiation required is either a mild or a decided *stimulation*, whereby the local blood supply is increased, nutrition improved, absorption of exudates and products of destruction hastened, and cell proliferation and the process of healing promoted. It is the tissues themselves that become the bactericidal agents, as a result of the reaction induced by radiation, the latter having no direct influence upon the organisms. The amount of radiation required for the stimulation of sound or comparatively healthy cells is likely to prove destructive to those of lowered vitality. The importance of attending to all avenues of reinfection, and of always employing the *x*-ray applications as a local measure in conjunction with the accepted routine general measures so essential in the treatment of tuberculous patients, should always be borne in mind.

Applications in Dermatology.

Condition.	Indications for x-ray treatment.	Reaction necessary or desired.	Results.
A. Hair follicles.			
1. Hypertrichosis.	Epilation.	Partial, and occasionally nearly complete destruction of follicles, requires a mild degree of dermatitis.	Satisfactory in some instances; attended by considerable risk of dermatitis and subsequent atrophy of skin.
2. Sycosis.	Epilation, for drainage and to permit of easier access of local applications.	Mild applications until hairs loosen; avoid any decided reaction. No effect on organism.	A satisfactory and painless method of epilation.
3. Favus; tinea tonsurans.	The same.	Mainly stimulation; possibly some destructive effect on cells of lowered vitality.	Not advisable as routine measure.
B. Inflammatory.			
1. Acute eczema.	Inadvisable, except occasionally, for itching when other measures fail.	Mild stimulation.	May do harm except where especially indicated.
2. Chronic eczema.	Indicated only when other measures fail.	Mild stimulation.	Often successful where other measures fail.
3. Psoriasis.	When lesions are not too widespread, and condition is rebellious to usual local measures.	Mild stimulation.	Excellent results in some cases and no benefit in others.
C. Glandular hyperactivity.			
1. Acne vulgaris.	In cases rebellious to simpler measures.	Atrophy and diminished activity of sebaceous glands. Treat cautiously.	Very satisfactory; excellent cosmetic results. Danger of atrophy of skin.
2. Acne rosacea.	The same.	The same.	Fairly satisfactory in action on glands and follicles; less successful in reducing telangiectases.
3. Hyperidrosis.	The same.	Mild intermittent applications to reduce hyperactivity of glands.	Fairly satisfactory.
D. Ulcerations.			
Simple or indolent ulcers.	The same.	Mild stimulation.	Very efficient frequently.
E. Newgrowths.			
1. Lupus vulgaris.	See tuberculosis.		
2. Lupus erythematosus.	Always worth trying when ordinary measures fail.	Always try mild radiation first; treatment long continued; decided reaction usually necessary.	Radiation as efficient as any other measures, but cases are always rebellious.[1]
3. Leprosy.			No effect whatever, at least in curing the disease. Occasionally satisfactory results obtained.
4. Mycosis fungoides.			
5. Keloids and hypertrophied scars.	The most satisfactory method of treatment.	Destruction of abnormal cells by selective action; treatment long continued; skin reaction the guide.	Results very satisfactory, especially in conjunction with excision, as postoperative measure.
6. Paget's disease.	In usual seat, the breast, operative measures should always be given preference.	Destructive action, practically the same as in epithelioma.	May be successful when treatment is justifiable.
F. Vascular nevi.	When treatment is safe and promises results and other measures not possible or successful.	Obliteration of small vessels; requires prolonged and severe treatment, with reaction amounting practically to a dermatitis.	Results not very satisfactory as a rule.

[1] According to recent reports, the *local* lesions of leprosy have been favorably influenced by radiation in many instances, but a severe reaction seems necessary to produce any effect.

In *lupus vulgaris* radiation is the most satisfactory and successful treatment, being superior to even the Finsen method, and it may be regarded as practically a specific in this once much-dreaded disease. In *tuberculous adenitis* its value as a local measure is second only to that in lupus, and it may be employed either alone or in conjunction with operative procedure, as may be indicated in each case. In *tuberculous laryngitis*, unless used *most cautiously*, it is likely to do harm, but when carefully applied, Röntgen treatment will usually be of some benefit, although permanent cures are very rare because of the presence of a constant source of reinfection. *Pulmonary tuberculosis* has been benefited and even cured when *x*-ray treatment has been employed, but the part the latter plays in such results is always questionable. In *tuberculous peritonitis*, radiation has frequently been used to great advantage, especially in conjunction with operation. In *bone and joint lesions* it has practically no value. In *tenosynovitis* good results have been obtained. In *tuberculous cystitis* it may occasionally do some good, and it has frequently been employed to advantage in *tuberculous orchitis*.

Malignant Growths.—There are four general methods to be considered in the treatment of malignant disease: Radiation may be used alone in preference to operation or other local procedures; *anti*-operative applications; *post*-operative treatment; or as a palliative measure. The therapeutic effect depends upon the destructive or inhibitory action of the rays upon the malignant cells, without serious damage to the normal cells of the part.

Superficial Epithelioma.—When such lesions are accessible to direct radiation, and are not in localities where glandular metastasis is to be seriously considered, *x*-ray therapy, either alone or following partial removal of the growth by operation or freezing, is, as a rule, not only successful, but the most satisfactory method of treatment, especially as it yields the best cosmetic results. Its use alone is not permissible in those localities where *early* glandular metastasis is the rule, as in operable lesions of the lower lip or the penis, for example. Radiation may often be used to advantage as a postoperative measure in such cases, however, or as more or less of a palliative measure in hopeless inoperable cases.

Carcinoma of the Breast.—The employment of *x*-ray treatment in preference to operation in operable cases of mammary carcinoma is to be condemned, because, in the first place, this is an instance in which early metastasis is the rule and delay is to be avoided, and secondly, such a practice tends to prejudice the lay mind against early operation. Radiation has been employed as an anti-operative procedure, but its value in this connection has as yet not received wide recognition. Its most important use is undoubtedly in postoperative treatment. It is a valuable measure in the palliative treatment of hopeless cases.

Carcinoma of the Uterus.—Radiation may prove of value as a postoperative measure occasionally, either in preventing a recurrence in rare instances, or in retarding the progress of a recurrent growth. It

may be employed to advantage sometimes as a palliative measure in hopeless cases.

In carcinoma of the stomach or intestinal tract *x*-ray treatment is valueless. In epithelioma and papilloma of the bladder it may be used palliatively or as a postoperative measure when the rays can be directed through a suprapubic wound, and rarely it has been successful when so used. In connection with growths of the tongue, jaws, antra, mouth, or upper air passages it may be of some value as a postoperative measure, and is often useful palliatively.

Sarcoma.—As a rule, the best results in sarcoma follow the judicious combination of operation, radiation, and injection of Coley's fluid, but the results in general are extremely variable, and distant metastasis is always likely to prove a discouraging termination of a promising local result. Radiation should never be the means of delaying amputation when the latter is indicated in cases of sarcoma of the bones of the extremities.

Goitre.—In *exophthalmic* goitre the results of *x*-ray treatment have been extremely variable. Nothing need be expected except by very prolonged radiation. It has been used alone or in conjunction with operation, either before or after, or both. In *simple* goitre the results have been very much the same as in the preceding type when radiation alone has been employed, but unless prolonged, the treatment does no good. In the *cystic* type *x*-ray treatment is not applicable, as it has little if any effect.

Diseases Referable to the Blood-making Organs.—*Leukemia.*—In either variety of this condition *x*-ray treatment is the only one worth considering at the present time, but its use is not advisable in acute cases, acute relapses, or in cases in which toxemia is extreme and the end near at hand. There is no absolute proof that a permanent cure has ever been effected, but radiation has sufficient advantages when indicated to warrant its employment in preference to other measures. The treatment should be administered with due caution, as the careless or injudicious use of radiation in this disease has hastened death in a number of instances. In view of the present accepted belief that the primary seat of the disease is the bone marrow, the treatment should be directed mainly to the bones rather than to the secondary manifestations or metastases in the lymphatic structures and spleen.

Pseudoleukemia.—Radiation is also the treatment of choice in this condition. The applications are to be made locally to the enlargements, and the treatment carried out much after the same manner as in dealing with a malignant growth. Toxemia is likely to follow the early applications, and care should be taken to avoid it as much as possible.

Polycythemia.—Polycythemia may be benefited to a certain extent by treating the cases in the same manner as advised in leukemia, and for the same reason.

Anemia.—Splenic anemia has manifested only temporary improvement under *x*-ray treatment. Some cases of *pernicious anemia* have been

benefited by radiation over the bones, but any *x*-ray applications are unsafe in very toxic or otherwise bad cases.

Anodyne Effect.—*X*-ray applications have frequently afforded temporary or even permanent relief from pain in obstinate cases of neuralgia of functional or uncertain origin, neuritis, and herpes zoster. Partial or complete relief from pain is a well-organized effect of radiation in the treatment of malignant growths, and is noticeable in perhaps the majority of instances. Radiation is frequently most efficient in curing obstinate cases of *pruritus.*

CHAPTER XXXI

DANGERS ATTENDING THE USE OF X-RAYS

Aside from certain general effects that may follow the use of *x*-rays as a therapeutic agent, whether the application be for therápeutic or occasionally for diagnostic purposes, as in connection with some few conditions already mentioned, such as leukemia, pernicious anemia, and pneumonia for example, there are a number of far more common dangers to which both patient and operator may be constantly exposed, and to avoid which certain definite precautions must be constantly observed. So far as is known at the present time, the structures that are likely to suffer primarily in this way are the skin and its appendages, the testicle, and the eye.

X-RAY DERMATITIS

The skin is the structure most commonly affected by excessive radiation, and the most frequent manifestation, therefore, of excessive exposure is the *x-ray dermatitis,* of which there are two distinct types—the acute form, often improperly called the "*x*-ray burn," and the chronic type of dermatitis which follows prolonged mild exposure. Of the former, which is the result of too vigorous radiation within a short period of time, the patient is usually the victim, while the latter is more commonly an affection of the *x*-ray operator.

Varieties.—*Acute* dermatitis is relatively far less common now, perhaps, than in the earlier history of Röntgenology, and mainly for the reason that it is now possible to determine and control the quality and quantity of the *x*-ray output. Based upon the severity of the reaction and resulting lesions, four degrees of the acute dermatitis are recognized. A lesion of the *first* degree is the manifestation of a mild reaction in the skin, and the essential pathological feature is an active hyperemia. It is attended by more or less burning and often itching, and the skin presents somewhat the appearance seen in the acute stage of a sunburn. Usually this reaction is not of a serious nature, and subsides in a few days if the cause has ceased and it is properly treated. On the other hand, it may be followed by epilation, which is rarely permanent, or it may be simply the first stage of a more severe reaction. A *second degree* dermatitis represents an active inflammatory reaction. Congestion follows hyperemia, and the bright red color becomes more of a dusky hue, while the burning is more intense and there may be actual pain. In this,

also, resolution usually takes place under proper care, although not so soon, but more severe manifestations may follow, the skin becoming more dusky in appearance, swollen, or even edematous, followed later by the appearance of discreet vesicles which may or may not become confluent. Under such circumstances, resolution is still possible with careful treatment, but, on the other hand, the area of vesiculation may become the seat of a typical *x*-ray ulceration, especially if the condition has not received the proper care and treatment. Pain is apt to be severe. Epilation is an invariable sequela, while still later ones may be atrophy of the skin (glandular), pigmentation, scaliness, and telangiectasis. The *third degree* lesion is the *x*-ray ulceration which may follow the preceding reactions. In its extent it affects the skin and even the subcutaneous tissue to a certain depth. The characteristic features of such an ulcer are its sharply defined irregular and inflamed edges, which have little or no tendency to heal, and a base covered by a characteristic yellowish or whitish tenacious slough which often has the misleading appearance of new skin. The thickness of this slough depends upon the severity of the reaction and depth of the ulcer. The discharge is thin, crusts readily, and is scanty. Pain is apt to be intense. The *fourth degree* is represented by the same type of lesion, but the ulceration involves deeper structures. Healing of these ulcerations is the exception and not the rule, and excision and subsequent skin grafting are usually required, after waiting a reasonable length of time.

A characteristic feature of all these reactions and results is their latency. A dermatitis may appear anywhere from two days to several weeks after the exposure which caused it, the average or usual period being four or five days, hence any continuance of radiation during this latent period will result in a more severe reaction. For this reason exposures should not be made too severe or too close together, and especially in the early part of the treatment, until the possibility of unusual susceptibility of the patient's skin can be eliminated. All cases of *x*-ray dermatitis should receive prompt treatment, but only by one thoroughly familiar with the care of this condition.

Chronic dermatitis differs materially from the acute type in many respects. It is the result of long continued excessive but mild exposure, and is more commonly an affection from which the operator suffers. With a few exceptions, the exposed portions of the body have been the only ones seriously affected, and the skin of the hands seems to be far more susceptible than that of the head and face. In the cases of almost all of those whose hands have been affected, serious lesions have not appeared above the lines of the cuffs, showing that clothing is an efficient filter for the very soft rays. Of all the sources of exposure, that attending the use of the fluoroscope is by far the most potent factor in the production of the chronic dermatitis of the operator, and this is no doubt the main reason that the hands are usually the most frequent seats of the lesions. Other more constant but less effective sources of exposure are the careless or injudicious direct exposure to radiation

from the tube and to secondary radiation from the walls of the room and all objects contained therein. Undoubtedly the cumulative effect of the radiation from these sources upon the hands is further intensified by the irritation of the skin arising from contact with developing solutions.

Pathology.—The pathological aspect of this condition has been carefully studied, but only its more important pathological features can be considered here. It may be said that the true chronic dermatitis is preceded by a more or less acute stage which is characterized by a prolonged but very mild inflammatory reaction. At a subsequent period the microscope has shown degenerative changes in the epithelium, this being more pronounced at first within and immediately around the follicles until they undergo partial or complete atrophy, which is attended by a loss of the hair. The matrix of the nail, likewise, suffers early. Later on, there is both thinning of the epidermis, attended by ulceration and the formation of cracks and fissures, and increased cellular proliferation in certain areas, as a result of which the horny layer becomes hypertrophied and heaped up in the formation of keratoses. Pusey and others regard this condition of chronic dermatitis as of the nature of a presenile keratosis, and somewhat analogous with the rare condition known as xeroderma pigmentosa. At a later period columns of epithelial cells may be found projecting into the corium, especially around the bases of ulcers and keratoses, and this is regarded as representing a precancerous stage. In the corium the connective-tissue cells also exhibit degenerative changes, and there is more or less leukocytic infiltration and subsequent cell proliferation, followed by cicatrization and contraction. The smaller *bloodvessels* exhibit very characteristic changes. Some of the cells of the intima, and to a less extent those of the media, show degenerative changes, and the former are apt to encroach more or less upon the lumen. Later on areas of cellular proliferation are found in different parts of the intima, and sometimes in the media. As a result of these changes the lumen may become obliterated, and aside from uncertain trophic disturbances, this interference with the local blood supply and nutrition plays perhaps the most important part in the loss of vitality of the skin. Although there is an attempt made to regain the lost vascularity through the formation of new vessels, these are, as a rule, poorly developed, having imperfect walls, which rupture easily and do not contract readily, so that they bleed readily and profusely. Throughout the entire process the epithelial structures are the ones that are the real sufferers. Under the influence of radiation at the start, they undergo degenerative changes, with resulting impairment of vitality and glandular atrophy, while the connective-tissue cells and those of the bloodvessels may undergo proliferation. Subsequently the epithelial cells are prevented from regaining their lost vitality because of impaired nutrition from deficient vascularity, cicatrization, and probably certain trophic disturbances which have not yet been demonstrated.

Clinical Aspect.—As previously stated, the skin of the dorsum of the hands and fingers is the most frequently and the most seriously affected. The preliminary stage of a mild inflammatory reaction is characterized by redness, burning, and itching. The redness is most marked on the backs of the phalanges, and especially around the nails, while on the dorsum of the hand it is apt to appear first in the form of macular spots which correspond to the orifices of the glands and follicles. Later on, the hair disappears and the skin becomes dry and wrinkled as a result of glandular atrophy, and still later, stretched and shiny, following connective-tissue changes in the corium, and telangiectases may appear. The cells of the matrix of the nails are affected very early, and the atrophic changes in this structure are manifest in longitudinal striation and ribbing of the nails, which also become brittle and crack easily at their ends, especially in layers. The nails grow more and more slowly, and finally become nothing more than rudimentary structures. After the redness of the skin has persisted for some time an occasional vesicle makes its appearance, at first on the backs of the phalanges. At first they will disappear, but ultimately one or more will persist and be followed by ulceration. At this period the skin is apt to crack readily over the knuckles, and these cracks may persist for a long time as fissures. The ulcers especially show little or no tendency to heal. Other portions of the skin will become scaly, and areas of keratosis will appear. The ulcers and fissures are exquisitely painful, due to either exposed nerve endings, actual neuritis, or pressure from cicatrization. The final stage is the development of epitheliomata at the bases of the constantly irritated and inflamed ulcers or keratoses.

Prognosis.—Recovery is slow at any stage, but the ulcers and keratoses are most difficult, or impossible even, to heal, and a continuance of *x*-ray work without practically absolute protection from exposure at all times is likely to end in the loss of fingers or even hands at the least, and may end in death. Porter, who has had an unusually large experience in dealing with cases of chronic *x*-ray dermatitis, states that: "Given lesions of sufficient duration and severity without adequate treatment, the future development of cancer can almost be postulated." Out of 47 cases of chronic *x*-ray lesions collected by him from his own practice, from literature, and from other sources, up to 1909, 4 presented a precancerous stage, 36 had developed unquestionable epitheliomata, and 2 had possible sarcomata. Out of the 36 cases with epitheliomatous growths, 9, or 25 per cent., had died as the result of internal metastasis. Since Porter published his report, several additional deaths have occurred from the same cause.

Preventive Measures.—The prominent part played by fluoroscopy in the etiology of these lesions should be a warning to the operator to at least limit the use of the fluoroscope strictly to those examinations in which it has no substitute in the radiograph, and even then it should be used as little as possible, and only when the greatest possible amount of protection from exposure to both direct and secondary radiation is

afforded. The fluoroscope should never be used merely for the sake of its convenience, at least by the operator. Aside from the use of the fluoroscope, all unnecessary exposure should be avoided, and a tube should never be used without an efficient shield. The protection afforded by the so-called *protective* gloves and all other articles of apparel that are on the market is more or less of a delusion. The most adequate general protection is afforded by a sheet lead booth with four lead walls and a lead roof. In this the switches may be placed so that there is no necessity for the operator to be outside while the tube is being excited. The coil should be in sight and the tube and patient should be observed by means of suitable mirrors. Such a device protects from *secondary* as well as direct radiation, which is not the case with the ordinary lead *screen,* and which is, therefore, an inadequate means of protection. The lead on the side of such a booth next to the tube should be at least one-eighth of an inch in thickness. Some operators prefer to stay in an adjoining room which has a leaded wall on the side next to the x-ray tube. In either case the patient and tube should always be under observation through suitable mirrors. A third important precaution should be observed in the dark room in the avoidance of all unnecessary contact of the hands with developing solutions. Whenever such contact occurs, either from necessity or accidentally, the hands should be rinsed off in water as soon as possible.

Treatment.—This should be intrusted to no person but one who is thoroughly familiar with the care of such lesions, and a statement of more than a few general facts in this connection would be inappropriate here. In all instances a removal of the cause, by either giving up x-ray work altogether or by the use of adequate protection, is essential. Dry dressings are preferable, as a rule, perhaps, although wet dressings frequently are better borne or prove more efficient. Above all, irritating applications of any kind should be avoided, and the same may be said of local anesthetics. All lesions should be protected against irritation and infection. Persistent keratoses had best be removed by freezing or excision, and especially if deep; while ulcers rarely heal, and had best be excised, therefore, and the areas subsequently skin grafted. In view of the rather high mortality, early amputation is the wisest course, as a rule, in cases of epithelioma.

OTHER EFFECTS

Sterility.—Among other frequent results of the same causes, but fortunately of a less serious nature so far as life or suffering are concerned, should be mentioned sterility of the male and injury to the eyes. Sterility is unimportant beyond the loss of the function of procreation. It is a well-recognized fact that at the time this effect of x-ray exposure was discovered the vast majority of active x-ray workers were sterile in the sense of having either non-motile spermatozoa or none at all.

It has been proved that this condition is not always a permanent one, however, provided the individual so affected either gives up x-ray work or employs suitable protection against subsequent exposure.

Conjunctivitis.—Conjunctivitis is the only effect that has been so far noted as the result of the exposure of normal eyes. Conjunctivitis is very apt to complicate the x-ray treatment of cases of orbital tumors or of epitheliomata of the lids. In the former it may arise very early, and lead rapidly to edema of the conjunctiva and even panophthalmitis and loss of the eye. The eyes of patients should always be adequately protected, and it is a wise plan for the operator to wear glasses of some kind to protect the eyes not only from radiation, but also from injury by accidental collapse of a tube.

In view of these injurious effects that are already known and well recognized, and the fact that it is the more highly specialized cells that are the most seriously affected, and especially the changes that have been observed in the smaller bloodvessels, it would seem rational to be on our guard against other more general and equally serious results that may be more latent in their appearance, and, therefore, not as yet discovered, which may follow still more prolonged mild exposure of the body. Among such possibilities might be suggested premature arteriosclerosis, sclerotic changes in the nervous system, and optic atrophy. Those who ridicule the sensible efforts now made by many operators for their protection against possible dangers yet unknown, as well as against those only too well known, may some day learn to their sorrow that precautions cannot be carried too far.

INDEX

D

E

F

L

M

N

O

P

Q

R

S

U

V

W

X

Z